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DEVELOPMENT OF POTENTIAL ROLES OF SUPERSONIC TRANSPORT CREWS

An Informal Report of the
STUDY METHODOLOGY

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

This report presents a synopsis of the methodological approach and techniques used throughout the entire contract, including results documented in the first three reports of this study (1,2,3), as well as in the present report. Much of the method used is explicit in the reports of the study, and this report is intended to synthesize or summarize the method. In addition to presenting the method used for the SST study, an attempt was made to generalize the method so that it might be applied to other studies concerned with the derivation or investigation of crew requirements in other manned systems. This general approach to study of crew requirements evolved during the SST crew requirements study and incorporates methodological improvements resulting from the study. Throughout this report, the general approach to a crew requirements study will be outlined after related aspects of the SST study.

Figure 1 is a schematic representation of the SST study efforts. A tabular summary for each of the 14 efforts is presented in this chapter. The SST study approach is presented on one side of the table and a general crew requirements study approach is presented on the other side. After each of these 14 summaries is a discussion of the SST study effort, followed by a discussion of a general study effort.

EFFORT NO. 1, DELINEATION OF SYSTEM REQUIREMENTS AND CONSTRAINTS

DISCUSSION OF THE SST STUDY EFFORT

Delineation of SST system requirements and constraints was accomplished by systematically interrogating various data sources.

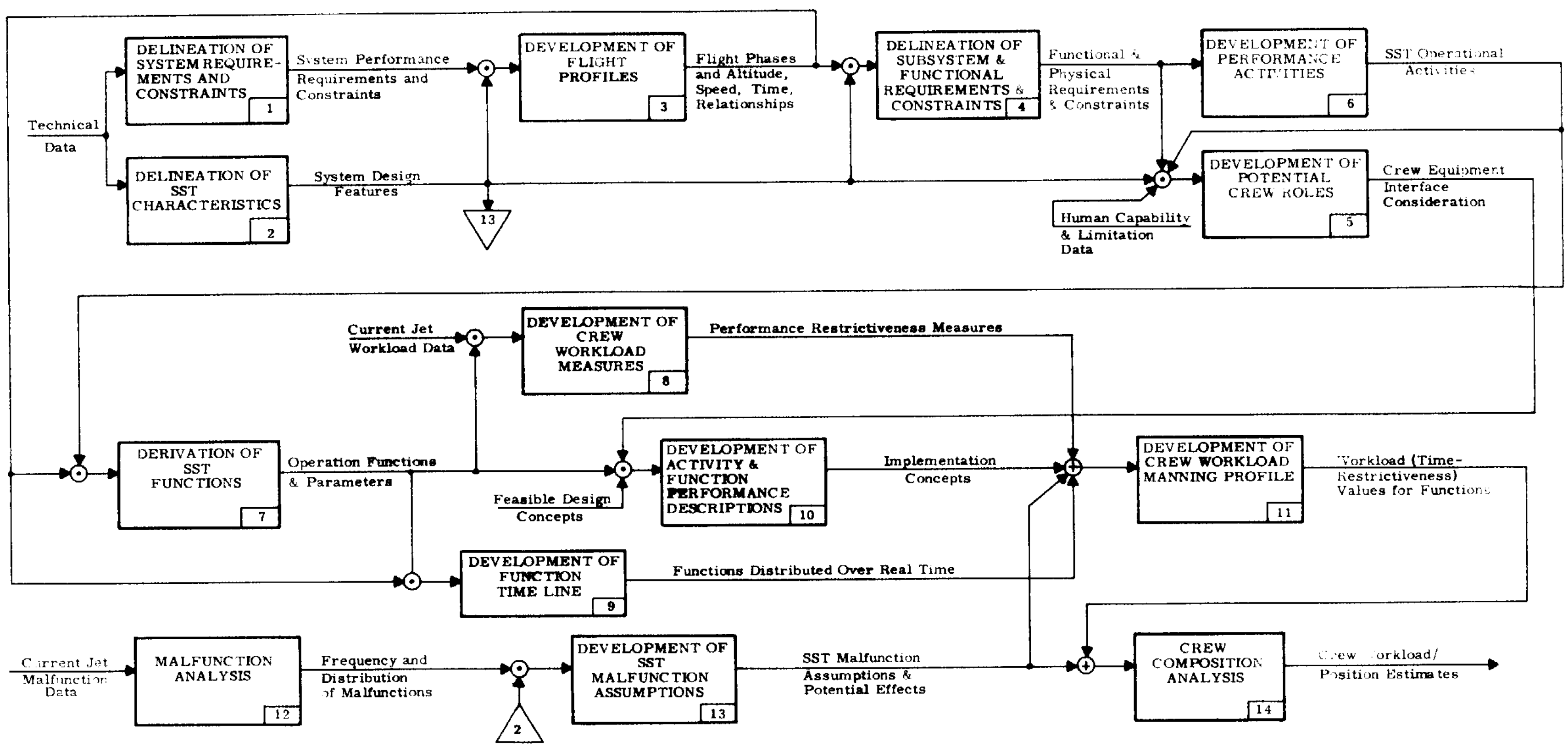

Figure 1. Principal Methodological Efforts in the SST Study.

SUMMARY OF EFFORT NO. 1

<table>
<tr><th>SST STUDY APPROACH</th><th>A GENERAL CREW REQUIREMENTS STUDY</th></tr>
<tr><td>EFFORT NO. 1. Delineation of System Requirements and Constraints</td><td>EFFORT NO. 1. Delineation of System Requirements and Constraints</td></tr>
<tr><td>INPUTS: Requirements and constraints expressed by responsible or cognizant organizations

OUTPUTS:
1. Collation of system requirements and constraints expressed by SST responsible or cognizant groups

METHOD SUMMARY:
1. Delineate SST requirements and constraints for:
(a) System performance
(b) Noise
(c) Compatibility with other systems and equipment
(d) Environment
(e) Flight crew complement and station
(f) Passenger compartment
(g) Operational support
(h) System effectiveness</td><td>INPUTS: Requirements and constraints expressed by organizations responsible for development and operation of the system

OUTPUTS:
1. Collation of system requirements and constraints expressed by responsible or cognizant development and operational groups

METHOD SUMMARY:
1. Delineate system requirements:
(a) Mission
(1) Static
(2) Dynamic
(3) Environment
(b) Physical
(c) Functional
(d) Reliability
(e) Logical consistency

2. Delineate system constraints
(a) Design
(b) Economic
(c) Temporal
(d) Utilization
(e) Social</td></tr>
</table>

The following categories of requirements and constraints were used and/or evolved for the interrogation.

1. System performance:
   - Payload
   - Range
   - Speed
   - Subsonic and supersonic flight
   - Noise

2. Environmental:
   - Pressure
   - Temperature
   - Radiation
   - Ozone
   - Meteorological compensation
   - Ground operational environment

3. Effectiveness:
   - Reliability
   - Maintainability
   - Operational life
   - Safety
   - Standardization

4. Compatibility with other systems and facilities.
   - Air Traffic Control
   - Airports

5. Support:
   Operational
   Maintenance

6. Economics

The following organizations were used for source material:

NASA	National Aeronautics and Space Administration
FAA	Federal Aviation Agency
ICAO	International Civil Aviation Organization
ALPA	Air Line Pilots Association
IFALPA	Internation Federation of Air Line Pilots Association
CAB	Civil Aeronautics Board
FEIA	Flight Engineers International Association
IATA	International Air Transport Association
AAAE	American Association of Airport Executives
AOC	Airport Operators Council
IANC	International Airline Navigators Council

Insofar as possible the specific requirements and constraints expressed by an organization or individual were quoted as we received them. Each specific requirement or group of requirements was reviewed and compared with today's jet operations. The comparison was made with respect to crew variables, operational variables, and flight deck design. Where these variables appeared to differ from today's jets, or were unique to the SST, specific statements or discussions were presented. Any requirement, or group of requirements, which was analyzed to be different from today's jets or unique to the SST represents an area where the impact on crew role may need more specific investigation.

DISCUSSION OF A GENERAL STUDY EFFORT

Delineation of system requirements and constraints is a process of systematic investigation. Anne Story (ref. 4) suggests four categories of criteria for evaluating man-machine systems: material, mechanistic, logical, and final. These criteria are excellent for system requirements and were used in building a general methodology for this effort. Analogous categories of system requirements are used in the general study approach, i. e., functional, logical, and mission requirements. In addition, reliability has been included as another category of requirements. The following categories of constraints are also used: social, economic, temporal, design, and utilization. It should be stressed that the precision with which any criterion is identified as a requirement or a constraint is not important as there is obviously some confusion in practice in attempting to classify criteria. It is only important to identify as many criteria as possible. In general, however, requirements refer to those criteria which relate to system performance. Constraints generally refer to those criteria which relate to the limitations under which the system must be developed and operated. The suggested general categories of requirements and constraints are defined below.

Requirements

1. Physical requirements. These refer to the physical components (machine or human) *per se* of a system. Physical requirements may be further categorized as material or human. In either case, these requirements are usually akin

to standards which must be met by the system design. Machine parts may be qualified with respect to load requirements, for example, of voltage, pressure, heating, etc. Analogously, human components may be qualified by such measures as age, height, weight, IQ, level of training, etc.

2. Functional requirements. System requirements are often expressed as the functioning of various subsystems which are described in terms of input and output boundaries related in a more or less temporal sequence. Functional requirements may, therefore, be expressed for various subsystems which operate on input information, materials, or energy, to transform, transfer, or transduce these inputs into outputs which may be expressed functionally. Thus the expression of the input-output boundaries of any subsystem in parametric terms is, in fact, an expression of a functional requirement.

3. Mission requirements. Mission requirements are those which refer to the total system goals or objectives. It has been found convenient to classify mission requirements as static, dynamic, and environmental.

    a. Mission static requirements. Mission static requirements refer to those expressions of system capability which may be expressed as scalar values. The use of the word static is a means of qualifying those requirements for the permissive aspects of the system rather than the performance (dynamic) aspects of the system. Static requirements refer to such factors as payload, volume, weight, etc.

    b. Mission dynamic requirements. Mission dynamic requirements refer to those expressions of system performance which describe what the system must do. The use of the term dynamic, qualifies these requirements as those involving the expenditure of energy in the accomplishment of some performance to meet the system objectives.

c. Mission environmental requirements. All systems will operate within some environment. Mission environmental requirements then are those expressions of the ranges of environmental factors and forces anticipated or known to be present during periods of system operation. These would be both atmospheric factors, such as pressure, radiation, temperature, etc., and physical factors and forces, such as noise, vibration, motion, etc.

4. Reliability requirements. These requirements refer to those measures of system effectiveness which can be used to express how well the system meets its other requirements. Thus the word reliability is being used in the broad sense and may actually refer to probability of mission success, availability, end commission rate, etc.

5. Logical requirements. Logical requirements constitute the principles for determining basic design compatibilities or the internal and external consistency of other requirements. "To increase the precision of an electronic guidance device very often means increasing its complexity and cost and decreasing its reliability. An important question for the system's designer is that of choosing the correct balance among the conflicting criteria" (ref. 4).

a. Internal consistency. These requirements refer to those logical relationships among the internal components, functions, or goals of the system. They may frequently express the trade-off criteria among incompatible requirements, e. g., space vs. weight.

b. External consistency. These requirements refer to the compatibility of system requirements with external systems with which the system, or the design, must interface. All systems under development interface with extant systems at some point in their utilization, and any requirements which affect this interface must be compatible.

Constraints

1. Social constraints. These constraints refer to the limitations on design, development, and operation because of cultural, moral, political, lingual, religious, or personnel factors.

2. Economic constraints. These refer to the economic limitations under which the system must be developed and operated.

3. Temporal constraints. These refer to the time based factors which affect either development or operational periods of the system.

4. Design constraints. These refer to preconceived or given design features which limit the degrees of freedom available in total system design.

5. Utilization constraints. These refer to given considerations with respect to facility, personnel, equipment, materials, etc., which also limit the degrees of freedom available for total system design.

The general categories described above can be used to systematically delineate system requirements and constraints.

Sources for obtaining system requirement and constraint data are typically available because considerable effort is frequently expended to define the system prior to the awarding of a contract for system development. Results of these definition studies are usually documented in one or more of the following types of documents:

1. Specific operational requirements
2. Advanced development objectives
3. Study reports; many factors related to the input and output states as well as changes of states of the system object are covered in these study reports. However, the problems are usually studied with a specific orientation and the analyst will have to place it in the context of the system. These may include intelligence studies concerning the vulnerability and defense capability of the targets or the various ways in which the target changes of states can be accomplished. The complexity of the analyst's job would depend to a large extent on the extent of coverage of these study reports. However, the results of the reports must be placed in the context of the overall system as defined by both the analyst and the system directive documents.
4. Study program directives
5. Study program plan
6. Request for proposal
7. Contractor's proposal
8. The contract and work statement

Another important source of information is the user group. Frequently, it is assumed that user groups will be biased towards their own specific problems and will tend to provide unnecessary constraints rather than be of assistance in the development of the system.

While this may often occur, it is also true that a system can only be as good as the personnel who use and maintain it. In addition, user groups frequently encounter problems with which the contracting group or the contractor are not aware. There are cases when unnecessary constraints can be established. However, these are primarily cases when the users' problems are accepted at face value and no attempt is made to examine the problems thoroughly. The user groups represent a potentially large source of information about the performance characteristics of the family of means. This potential will not be realized unless user groups are interrogated thoroughly for variables relevant to development, i. e., variables which can be controlled through development. System planners and designers frequently make the error of contacting only the management levels of user groups. This is unfortunate since users at the "working level" are usually aware of many problems with which management is not familiar. Furthermore, management and the working level have different perceptions of many problems. Both groups must be contacted if a valid representation is to be obtained.

EFFORT NO. 2, DEVELOPMENT OF SYSTEM CONFIGURATION

DISCUSSION OF THE SST STUDY EFFORT

The United States SST program is currently in a design competition stage between configurations proposed by the Boeing Company and Lockheed-California Company. Since the study described in this report was in no way concerned with evaluation of these two design configurations, the SST characteristics delineated were general enough to encompass both the variable-sweep and double-delta configurations proposed by Boeing and Lockheed, respectively.

SUMMARY OF EFFORT NO. 2

SST STUDY APPROACH	A GENERAL CREW REQUIREMENTS STUDY
EFFORT NO. 2. Delineation of SST Characteristics	EFFORT NO. 2. Development of System Configuration
INPUTS: 1. Technical data concerning potential SST configurations OUTPUTS: 1. SST system design characteristics expressed as nominal values METHOD SUMMARY: 1. Delineate SST typical physical dimensions 2. Delineate flight deck configuration 3. Delineate subsystem concepts	INPUTS: 1. Technical data concerning potential system configurations OUTPUTS: 1. System design configuration METHOD SUMMARY: 1. Delineate major subsystems 2. Define interrelation between subsystems 3. Develop "single thread" configuration 4. Develop "replicated" configuration 5. Develop synthesized configuration

DISCUSSION OF A GENERAL STUDY EFFORT

This effort is concerned with delineating the first cut design configuration for the system of concern. Configuration as used here is the broad system concept for operations and support. Ordinarily the operational and support concepts are generated by the customer representing the ultimate user.

System development usually proceeds through several levels of detail, but in general three levels of development are sufficient as a methodological basis. These three levels of system development are oriented toward the development of human performance within systems rather than hardware performance and are referred to here as (1) system analysis and design, (2) functions analysis and design, and (3) task analysis and design (ref. 5). System analysis and design is concerned with the derivation of subsystem requirements and constraints and the development of the role of man in the system configuration. Functions analysis and design is concerned with the derivation of subsystem functions and the allocation of these functions to men and machines. Task analysis and design is concerned with the derivation of human performance tasks and the design of the man-machine interface for accomplishing these tasks.

The effort under discussion is concerned with the first level of development and specifically with system design. There are many ways to approach this effort, but in general an acceptable approach should result in the delineation of major subsystems and their interrelationships. A technique for doing this at the functions level is described in detail under Effort 7, Derivation of SST functions. As a general approach, a technique for this step is described in Air Force Systems Command Manual 375-5, one of a series concerned with Systems Management. This technique results in "Top Level" and

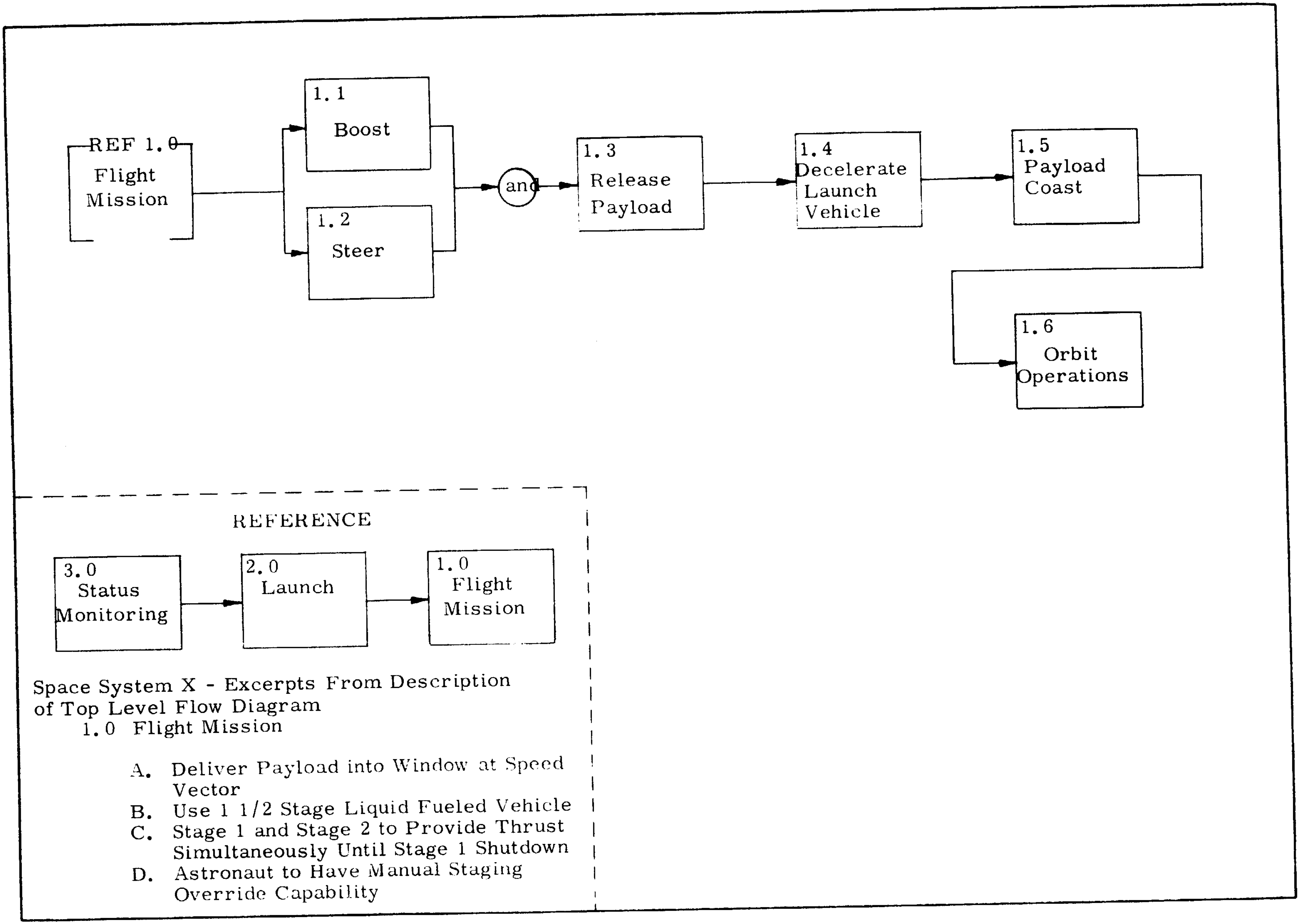

Figure 2. Example of "First Level" functional diagrams (taken from ref. 7)

"First Level" functional diagrams, an example of which is shown as Figure 2.

In addition to delineating subsystems and their interrelationships this effort should also be concerned with the development of system scope. This concept is described in Reference 5 as follows:

> For many large scale man-machine systems development may also take place with respect to scope (lateral development). For example, the New York Stock Exchange consists of many replicated units throughout the United States. Each of these units takes actions and processes information locally, and transmits information to and receives information from a central unit. The FAA, as an information processing system, is another example. This process of developing many units will be called Development of Scope. Development of scope may be necessary at any level of development of detail from entire systems through subsystems, functions and tasks. The development of scope is considered to occur over a three step range, i.e., single thread, replication, and synthesis. Similar to the development of detail, it is not important for the development of scope that a particular system development effort may not fall into three different levels. It is important that one recognize that there are different degrees of complexity as design solution of different levels of detail are replicated and synthesized.
>
> The first step in the development of scope is single thread development. This is essentially the simplest version of the real system which will operate on the basis of single inputs to produce criterion outputs with the required system reliability. The single thread design for a fleet of supersonic transports for example would be all of the personnel, equipment, facilities, and information it would take to operate and support a single vehicle (see Figure 3). The second step in the development of scope is the replication of the whole systems, subsystems, functions, or task designs that would be required to meet the (system requirements)[1] . . . . The supersonic transport fleet operation for example may require replication of the total system (vehicle and ground support) some subsystems (communications for example) and some functions and task level designs. The third step in the development scope is the synthesis of the replicated designs into a

[1] Parenthetic insertion ours.

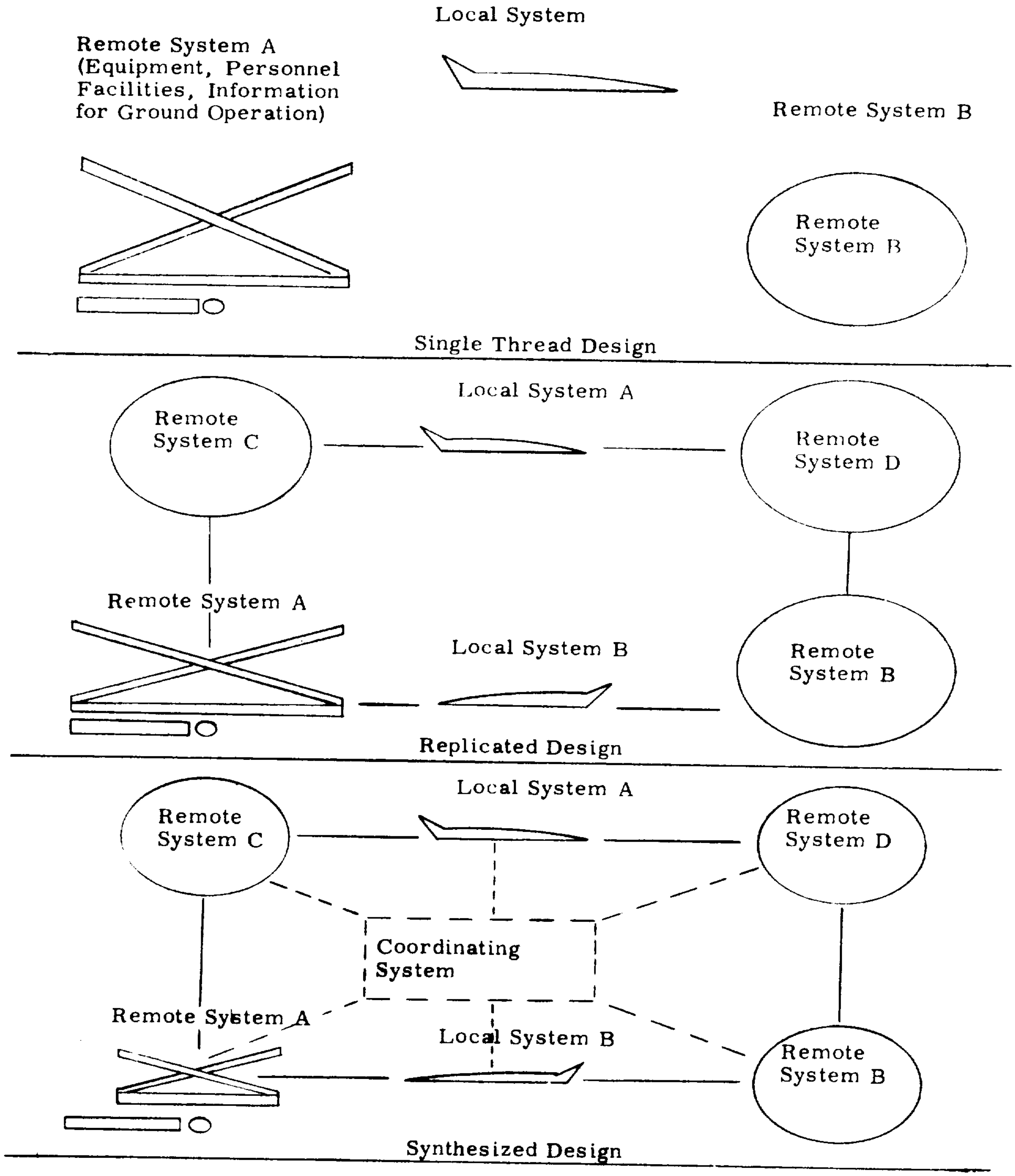

Figure 3. A simplified illustration of development of scope at the system level of detail for a supersonic transport fleet (taken from ref. 5).

complete system operation. It is more than likely that the replication of designs at any level may generate requirements for coordination and control which did not exist previously. To continue with the supersonic transport fleet example, the replications of airborne and ground equipment, facilities, personnel and information for the operation of many aircraft to many terminals obviously requires a great deal of scheduling, dispatch coordination, enroute control, and terminal area coordination and control in order to synthesize the replications into an effective complete system. Most of the synthesizing performances are obviously FAA activities in this simplified example.

To reiterate, the system development process must encompass both the development of detail and of scope. The detail development efforts are referred to as subsystem, function, and task levels and the scope of development efforts are referred to as single thread, replication, and synthesis steps. Most exploratory or experimental systems are developed in detail and there is little necessity for the development of scope.

EFFORT NO. 3, DEVELOPMENT OF MISSION PROFILES

DISCUSSION OF THE SST STUDY EFFORT

An SST operational flight was divided into different operational phases along a relative time continuum. The basic operations of the SST are sequential in nature and thus lend themselves readily to partitioning in this manner. Flight phases were developed to completely define the flight regime in terms of phases which begin and end with specific operational events or situations.

The SST flight profile obtained depends entirely on a specific aircraft configuration and payload, the particular route being flown, and atmospheric conditions which exist along the route. The profile information provides an orientation to SST performance and a base line for later analysis.

SUMMARY OF EFFORT NO. 3

SST STUDY APPROACH	A GENERAL CREW REQUIREMENTS STUDY
EFFORT NO. 3. Development of Flight Profiles	EFFORT NO. 3. Development of Mission Profiles
INPUTS: 1. SST system design characteristics 2. System requirements and constraints OUTPUTS: 1. Flight phases descriptions 2. Flight profiles METHOD SUMMARY: 1. Delineate flight phases 2. Develop performance and/or environment boundaries for each phase 3. Develop typical time altitude and altitude-distance profiles 4. Develop flight phase descriptions	INPUTS: 1. System design configuration 2. System requirements and constraints OUTPUTS: 1. Mission phases descriptions 2. Mission profiles METHOD SUMMARY: 1. Delineate mission phases 2. Develop performance and/or environment boundaries for each phase 3. Develop typical mission profiles against relevant base(s) 4. Develop mission phase descriptions

No particular route of flight was chosen for the flight profile developed here. Rather, a maximum range flight of 4000 statute miles was used as the basic route. As far as meteorological and atmospheric conditions are concerned, all data were developed on the basis of a standard day and a no wind condition using U. S. Standard Atmosphere Data (1962) as a basis for any calculation.

Generally, the optimum flight path for SST performance will be dependent on aerodynamic efficiency and fuel economy within the structural limitations of the aircraft. However, the optimum flight path cannot be flown in commercial operations because of considerations of sonic boom and air traffic control. Figures 4 and 5 are the general profiles or, more correctly, flight envelopes for the SST.

The flight profile phases derived were arbitrary and the particular phases used were developed principally because of their logical distinctions and their utility to the general objectives of the program, rather than because of radically different performance aspects during each phase. The twelve different flight phases used in this study are listed below.

1. Takeoff
2. Initial climb
3. Subsonic climb
4. Transonic acceleration
5. Supersonic climb
6. Cruise
7. Supersonic descent
8. Transonic deceleration
9. Subsonic descent
10. Letdown
11. Approach
12. Landing

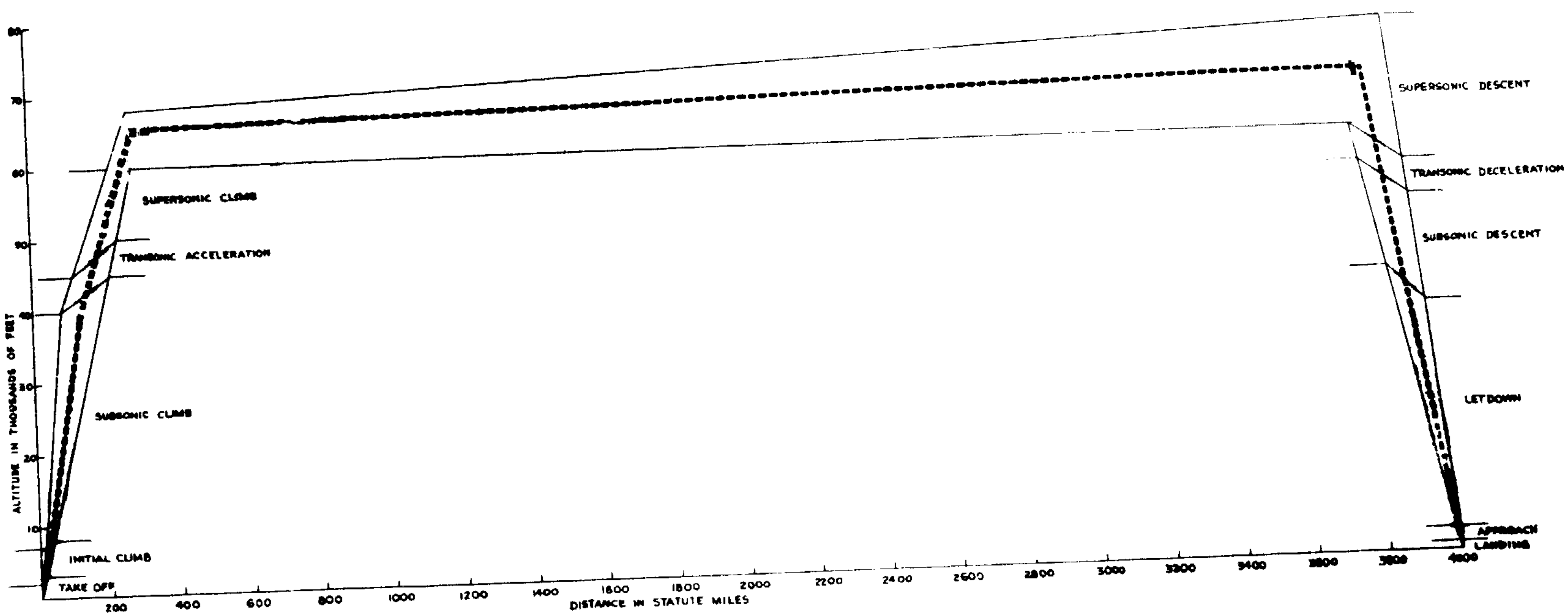

Figure 4. SST altitude-distance profile (taken from reference 1)

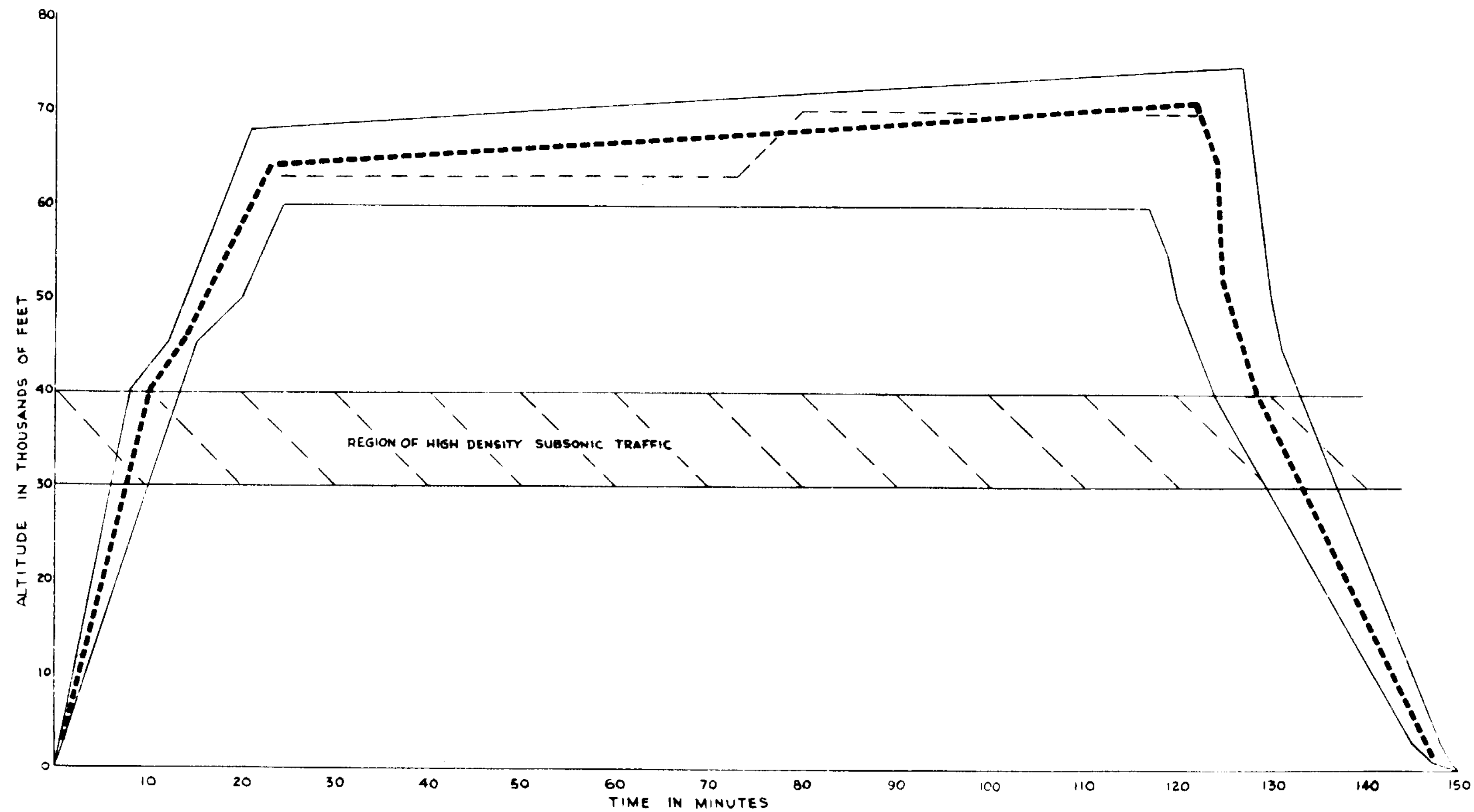

Figure 5. SST altitude-time profile (taken from reference 1)

The flight phases were described in terms of typical performance characteristics, aircraft characteristics, environmental conditions, air traffic control situation, airport characteristics, and occasionally, problems which might be expected.

DISCUSSION OF A GENERAL STUDY EFFORT

Mission profiles are generally developed by partitioning the total operation mission into a sequential series of distinct phases bounded in terms of critical events or environmental phenomena. The phases are plotted against a meaningful base, usually elapsed mission time or distance. The phases may also be plotted against a second dimension, e. g. , altitude. Mission profiles may be as detailed as necessary and several profiles may have to be developed to account for all mission requirements or detail. Reference 6 discusses the mission profile technique and provides some basic illustrations which are included here as Figures 6 and 7. Reference 6 discriminates between these two types of profiles; Figure 6 is a mission phase description and Figure 7, a mission phase segment description. Mission phases should be described in as much detail as possible using system operational parameters, mission environmental phenomena, and unique operational considerations and problems.

EFFORT NO. 4, DELINEATION OF SUBSYSTEM FUNCTIONAL REQUIREMENTS AND CONSTRAINTS

DISCUSSION OF THE SST STUDY EFFORT

The delineation of SST subsystem and functional requirements and constraints was very similar to Effort 1, delineation of system requirements and constraints. For this study, in fact, the two efforts were done essentially at the same time. Since Effort 4 concentrated

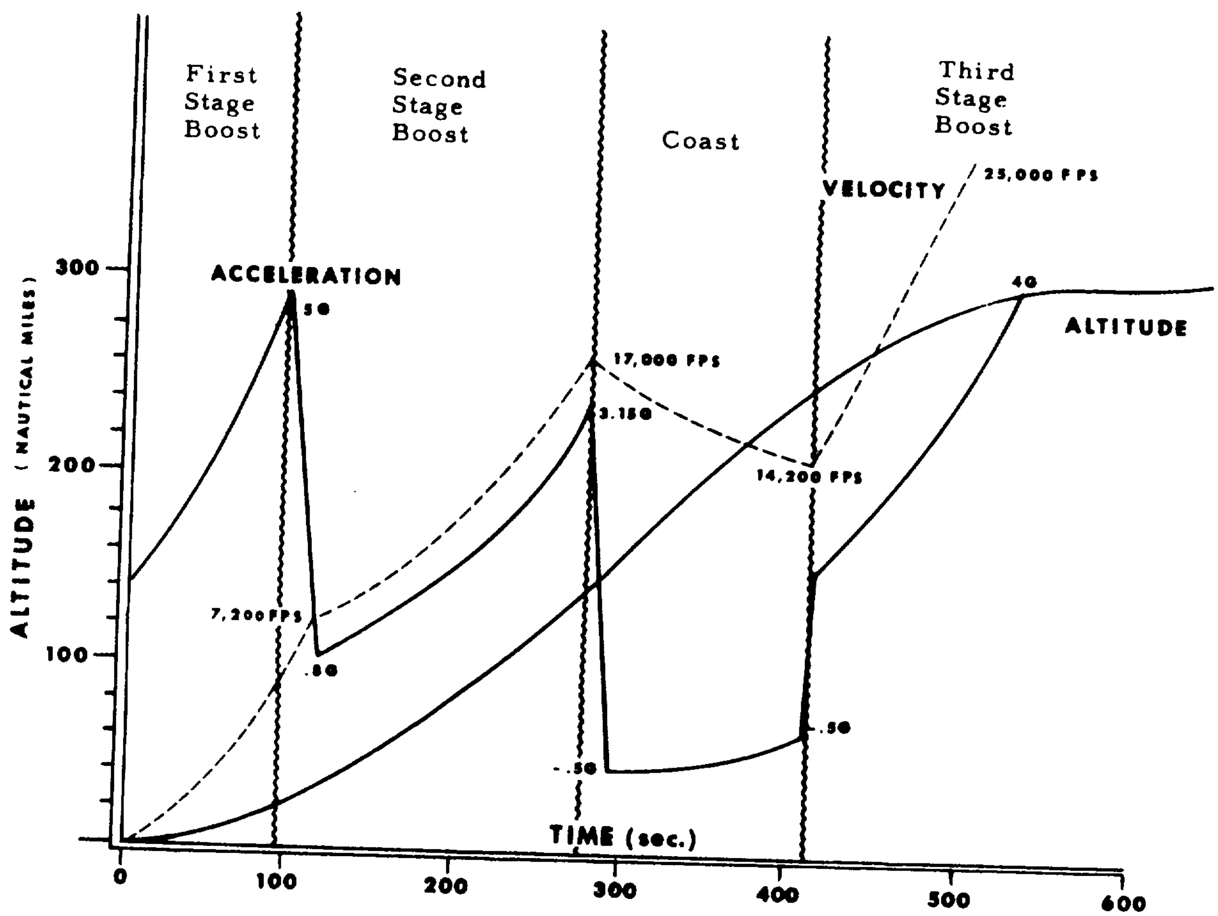

Figure 6. An example of a mission phase description (taken from ref. 6).

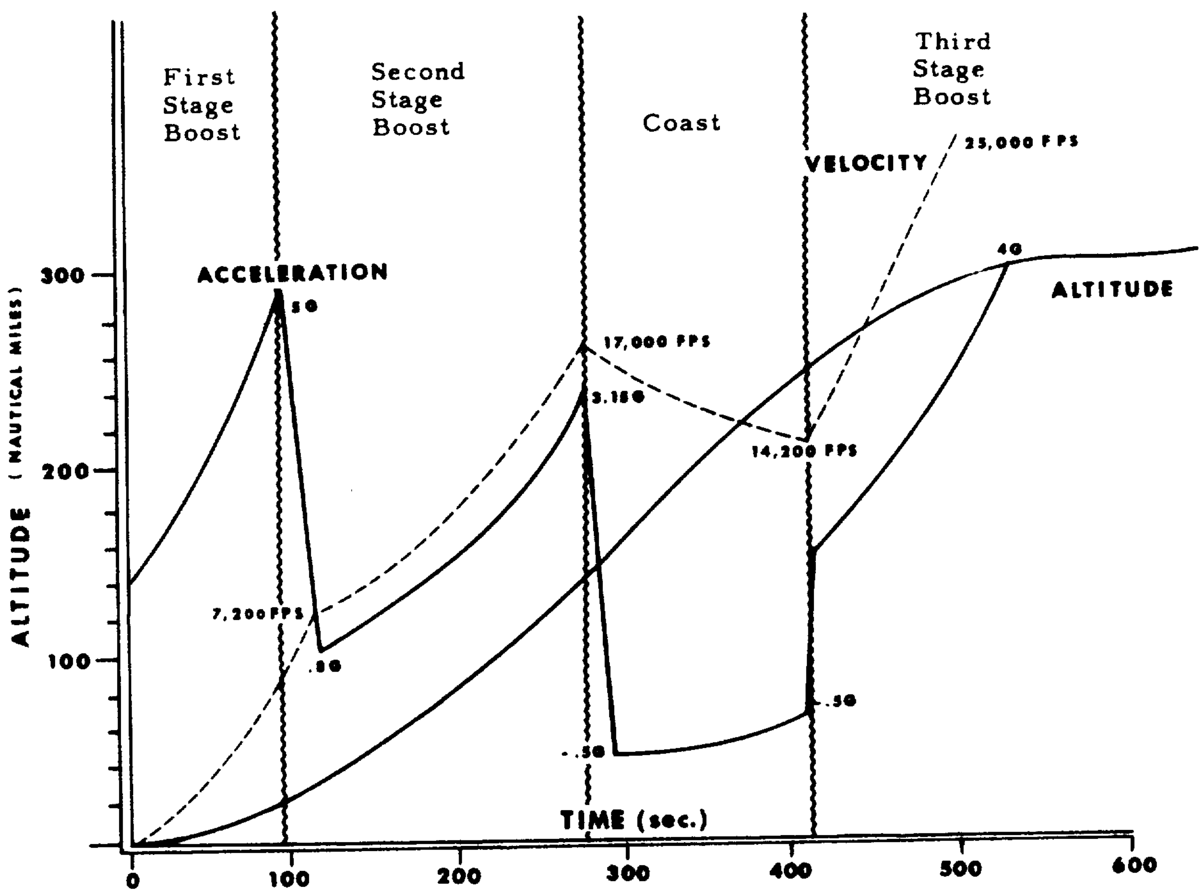

Figure 7. An example of a mission phase description (taken from ref. 6).

SUMMARY OF EFFORT NO. 4

SST STUDY APPROACH	A GENERAL CREW REQUIREMENTS STUDY
EFFORT NO. 4. Delineation of Subsystem and Functional Requirements and Constraints	EFFORT NO. 4. Delineation of Subsystem and Functional Requirements and Constraints
INPUTS: 1. SST system design characteristics 2. Flight profiles OUTPUTS: 1. Subsystem physical requirements and constraints 2. Functional requirements and constraints METHOD SUMMARY: 1. Delineate requirements and constraints for major aircraft subsystems 2. Delineate requirements and constraints for flight phase performance	INPUTS: 1. System design characteristics 2. Mission profiles OUTPUTS: 1. Subsystem requirements and constraints 2. Functional requirements and constraints 3. Exterior system interface requirements and constraints METHOD SUMMARY: 1. Delineate requirements and constraints for major subsystems 2. Delineate requirements and constraints for mission phase performance 3. Delineate requirements and constraints for interface with other systems

on subsystem and functional requirements and constraints, it was necessary to have the system characteristics delineated and two flight profiles developed before the effort could be effectively accomplished. The following categories were used and/or evolved for Effort 4.

1. Functional requirements:
   - Takeoff and climb
   - Cruise
   - Approach and landing
   - Flight planning
   - Speed

2. Subsystem requirements:
   - Flight control
   - Navigation
   - Communications
   - Power plant
   - Fuel
   - Hydraulic
   - Pneumatic
   - Electrical
   - A/C Ground control

3. Flight crew requirements:
   - Protection
   - Qualifications
   - Training
   - Flight deck

4. Passenger requirements:
   - Passenger protection and comfort
   - Interior design

DISCUSSION OF A GENERAL STUDY EFFORT

Subsystem and functional requirements and constraints can be defined using the criteria and categories for system requirements and constraints described under Effort 1. For Effort 4, subsystems will have already been identified (Effort 2), and functional performance will have been identified (Effort 3), the requirements and constraints can be more specific than in Effort 1. Subsystems are also meant to include personnel so that any unique requirements pertaining to the crew (or passengers) should also be identified in as much detail as possible.

EFFORT NO. 5 DEVELOPMENT OF POTENTIAL CREW ROLES

DISCUSSION OF THE SST STUDY EFFORT

The approach used to develop requirements and constraints for potential SST crew roles was essentially the same as the general study approach discussed next. The reader is referred to the following discussion both for the SST as well as the general case.

DISCUSSION OF A GENERAL STUDY EFFORT

The principal emphasis of this effort is on the development of requirements and constraints for potential crew roles. A philosophy relevant to this effort has been expressed by Price, Smith, and Behan in a previous study by Serendipity Associates (ref. 5) which states in part as follows:

> Man-machine capabilities and limitations. Many approaches have been developed for analyzing man's capabilities and limitations with respect to system performance. Some approaches suggest that man and machines

SUMMARY OF EFFORT NO. 5

SST STUDY APPROACH	A GENERAL CREW REQUIREMENTS STUDY
EFFORT NO. 5. Development of Potential Crew Roles	EFFORT NO. 5. Development of Potential Crew Roles
INPUTS: 1 1. Human capability and limitation data 2. SST system design characteristics 3. SST functional and physical subsystem requirements and constraints 4. SST major operational activities OUTPUTS: 1. Requirements and constraints of potential crew roles METHOD SUMMARY: 1. Develop limitations which constrain crew effectiveness 2. Develop required crew performance roles 3. Develop responsibility, authority, and acceptance considerations for crew roles 4. Develop considerations of crew composition and qualifications 5. Develop considerations for flight deck concepts	INPUTS: 1. Human capability and limitation data 2. System design configuration 3. Subsystem, functional, and interface requirements and constraints 4. Major activity classes OUTPUTS: 1. Requirements and constraints of potential crew roles METHOD SUMMARY: 1. Develop limitations which constrain crew effectiveness 2. Develop crew protection and sustenance concepts 3. Develop required crew performance roles 4. Develop responsibility, authority, and acceptance considerations for major activities 5. Develop considerations for crew composition and qualifications 6. Develop considerations for crew compartment concepts

should be compared, for system performance, while others suggest that men and machines are not comparable but are complementary. Some suggest that man should be designed into the system where possible, others suggest man should be designed out of the system where possible. There are numerous controversial issues concerning man's capabilities and limitations for system performance. The philosophy adopted here is (1) that man has certain unique capabilities and limitations which cannot be compared against machines, (2) there are many types of performance in which man can participate or which can be automated, and (3) for those performances where man does participate there is an optimum design to complement his capabilities and limitations. In general it may be stated that the concept proposed here is to develop a design solution for trade-off which exploits man's capabilities and compensates for his limitations. Four questions must be considered:

1. What are the limitations that constrain man's use in the system? This question must consider both system and individual factors, such as the following:

a. Man comes in only one physical model and can only be integrated into the system concept as a physical whole, with certain general characteristics of size, weight, shape, strength, etc.

b. Man has certain performance limitations such as sensitivity, reaction time, number of information channels, rate of operation, environmental stress tolerance, etc.

c. There is a definite price to pay for maintaining reliable performance potential in man, in terms of training, maintenance of proficiency, manuals, handbooks, instructions and other job guides.

d. Man has physiological needs. His performance deteriorates rapidly when these physiological needs, such as nourishment, environmental protection, sleep, comfort, and general health are not satisfied.

e. Man has psychological needs. His performance usually deteriorates over prolonged periods of high stress or nonactivity, and can change significantly as a result of such psychological variables as motivation, frustration, conflict, fear, etc.

2. What systems performance requires man? It is assumed that there are some types of performance which must be implemented by man, at least within the present state-of-the-art. Shapero, Rappaport and Erickson[1] develop a criterion for deciding when man is required in the system. They assert:

> 'In any system (or function) of human design, man is necessary wherever the assumptions concerning the relationships between inputs and outputs are subject to re-examination and restructuring in the operational context.'

This criterion is restated 'in a more limited form for use in analyzing functions . . . . (page 21) as follows: In any system (or function) of human design, man is necessary wherever the form, and/or content of all of the inputs and outputs cannot be specified.'

We do not necessarily believe that this is the sole criterion, or that there is in fact a simple single criterion, but criteria can be developed to determine when man is required for system performance. For example, the lesson of the Mercury program can be stated as a criterion for human participation. In any system (or function) of human design, man is necessary wherever an automated performance possesses a high likelihood of failure or malfunction during the period of mission accomplishment.

3. What system performance could be implemented by man? This question is concerned with those kinds of system performance which can be done either (1) manually or by man with machine aids (mechanized) or (2) by machine alone (atuomatically). There are a wide range of system performances at all levels (subsystem, function and task) which can be performed by man or by machine. For example, consider the requirement for monitoring the electrical output of a piece of equipment. This monitoring may be accomplished automatically with comparator circuits or by man viewing the output on a display (mechanized). The optimum manned design should be developed and the choice between this and other designs (manned or or automatic) must be the choice between this and other

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[1] An approach to functions analysis and allocation. Stanford Research Institute. Contract AF33(616)6541. Project No. 9(88-7184), 1961.

designs (manned or automatic) must be based on trade-off's considering system effectiveness, reliability, cost, etc.

4. Given man's required (question 2) or feasible (question 3) inclusion in the system, what can be done to use his unique capabilities to maximize his performance reliability in the system? This question is concerned with 'human engineering' in its grammatically correct sense, i. e., we can 'engineer the human' to affect his performance. True --we cannot lengthen his arms, increase his range of auditory perception, or make him do things he is not intrinsically capable of, but we may 'engineer' his attitude. This can be accomplished by actually changing his attitude through psychological techniques or designing acceptance features into the system during development. Man has other unique capabilities, such as his ability to learn and to adapt, which must also be considered with respect to increasing system effectiveness.

Reference 5 also discusses in some detail considerations of human limitations, required crew performance roles, and unique human capabilities.

The limitations which constrain the crew's effectiveness should be the first consideration in developing potential crew roles for any system. Human limitations may generally be considered as anthropometric or ecological. Anthropometric constraints are probably obvious, but ecological constraints may be less so. Ecology is the study of the relationships among organisms and between them and their environment. The ecological relations between man and his environment place limits on man's ability to perform. The demands which an individual places on his environment may generally be classed as physical, physiological, and psycho-social. Reference 5 gives some examples of ecological constraints in these three categories as follows.

1. Among the physical constraints one may list:
   - Temperature control
   - Humidity control
   - Illumination control

Communications means
Protection from discomfort
Protection from danger
Potential for emergency escape

2. Among the physiological constraints one may list:
   Provision for potable water
   Provision for nutritive substances
   Breathing gases, oxygen, nitrogen, carbon dioxide, and water balance
   Ventilation
   Movement and exercise
   Accommodation of the human diurnal cycle
   Sanitation and bodily cleanliness
   Waste disposal, urine, feces, sweat, flatus
   Detection of long range aberrations in respiration, digestion, cardiovascular function, endocrine function, metabolism, dermatological changes
   Treatment for trauma and disease

3. Among the psycho-social factors one may list:
   Neurological stability
   Emotional stability
   Mental stability
   Maintenance of motivation
   Maintenance of alertness
   Provision for ingesting water and food
   Acceptance factors in waste disposal

In the case of the SST, human limitations were considered under two different headings: (1) those limitations of performance which result from an interaction of the performance environment and the human; (2) those performance limitations arising from characteristics of the vehicle.

Once the limitations which constrain the crew's effectiveness are delineated, consideration can be given to protection and sustenance concepts to compensate for these limitations. In those cases where the natural environment is hostile to man or where mission duration is long enough to require logistic support for human sustenance, compensating support requirements can be determined. Such requirements can then be evaluated as to the cost and effectiveness of protecting or sustaining man in a potential role.

The next consideration is the development of required crew performance roles. Man is usually required to participate in systems either because his presence is mandatory, or because he excels in some system situations. Where man is mandatory, there is no option for automation. However, where man excels in a system, there are options for automation, but a manned solution may be the best option.

In general, man's presence is essential to:

1. Achieve satisfactory system reliability.
2. Perform management and control tasks which require judgment as opposed to selection among specifiable and specific choices.
3. Perform non-system oriented tasks.
4. Increase the diversity of missions which the system is capable of achieving.

Even though man is not mandatory, many systems will include man's performance because the manned solution surpasses automatic performance. The areas in which man excels are varied and difficult to categorize and discuss. Price, Smith and Behan (ref. 5) note that while the literature contains many statements which compare men and machines, "these are two very large classes of things." They further discuss many qualifications which must be considered in comparing men and machines and indicate that man's role in system performance can only be evaluated within the context of a specific system. Nevertheless, three general roles for man in a system configuration have emerged:

1. Man can contribute to system effectiveness by operating system equipment. This may include starting and stopping, continuous control, adjusting, trimming or correcting, overriding part or all of a subsystem, switching to a standby or backup system, testing, and initiating and accomplishing emergency or non-routine procedures.

2. Man can substitute for system equipment. This includes such things as programming, sensing, selecting, storing information, monitoring system equipment, and performing manipulative actions unfeasible to mechanize.

3. Man provides capabilities not possible with an automatic system, such as observing and recording ephemeral information, anticipating failure and decision making. In general, man can function in situations in which alternatives cannot be specified in advance and therefore cannot be programmed in an automatic system.

Specific manned system performance can be investigated for any system of concern within the context of these three general roles.

For the SST crew, there is relative agreement about the roles in which man is mandatory. What is subject to controversy are those roles in which man is not mandatory, but may be used. This, of course, is basically a consideration of the automation problem--what should be automated and what should be left to the skills of the crew.

In a previous study (ref. 5) for the Ames Research Center, Serendipity Associates developed a rationale for the philosophy that there is an optimal manned design solution for any system requirement, i. e., there is an optimal role for man in any system. However, the optimal manned solution may not be the best over-all system solution when cost-effectiveness criteria are used to evaluate all solutions. The concept of an optimal manned solution is introduced here to point out the variables used in the Ames study (reference 5) to evaluate man's role. An optimal manned design solution was defined as "one in which man has the most responsible/authoritative/acceptable role which he can perform while also being protected and sustained." These three variables (i. e., responsibility, authority, and acceptance) are also useful to describe different potential roles for the SST crew with respect to major operational considerations.

Responsibility refers to the criticality or effect of role on mission performance and safety. In this usage, responsibility does not relate to the number of activities in which one is involved, but rather, to the criticality of the activities in which one is involved. The responsibility involved in the crew's role is directly related to the crew's accountability for critical activities.

The means which permit man to exercise control over his areas of responsibility or the manner in which he is assigned to manage his operational responsibilities constitute man's authority. The SST crew will be assisted greatly by the design of the airplane and its systems in a variety of areas of responsibility.

At this point it is desirable to distinguish between manual, mechanized, and automatic task performance. Manual task performance implies that a man performs the task, that he generates or accomplishes whatever power, energy, or energy transduction is required, and further that he controls the application of power or directs the utilization of the given energy. No assumptions are made about the nature of the task. It may utilize human receptors or effectors, or both. The definition does not preclude the use of tools (e. g. , a chart, a lever or a telescope) which merely extend man's raw capabilities.

Mechanized task performance implies that a man performs the task, while a machine generates or accomplishes whatever power, energy, or energy transduction is required, but that a man controls the application or directs the utilization of the given energy. Again, no assumptions are made about the nature of the task. In this case, the tool does more than extend man's raw capabilities. Examples are powered flight controls, search radar, a bottling machine or a desk calculator.

Automatic task performance implies that a machine performs the task by generating or accomplishing whatever power, energy, or energy transduction is required, and that a man controls the application of the power or directs the utilization of the given energy. In automatic task performance man plays a more remote role. He may determine what is to be done, and perhaps how, as in the use of a digital or analog computer. He may set the limits for an automatic control like a thermostat. He usually monitors the output to determine whether it meets certain minimal standards of accuracy. He initiates and may terminate the operation of the automatic device, as in the use of an autopilot or a record changer.

To return to the discussion of man's authoritative role, as used here, operational authority is concerned with the degree of automation of all activities for which the crew is responsible, since authority is essentially how activities will be performed and what part the crew will play. Specific means of performing specific functions will be the objective of the next phase of this study.

Man-machine system design has typically utilized data as to man's sensory, perceptual, cognitive, and motor capabilities in allocating functions to man or machine, and in designing interfaces. However, man's motivational system (i. e., acceptance) has not been systematically included in man-machine system design. This is a serious error because a highly motivated man can compensate considerably for poorly designed equipment and thus maintain system output. Conversely, a man who is dissatisfied with a machine function, due to status, economic, or survival fears, or who prefers to perform the function manually, may not properly use equipment which has been designed to fit all other criteria. Consequently, the system output may suffer.

Acceptance is extremely critical and will have a maximum effect on roles and system effectiveness. As the design of man's role is a major output of system design, it is important to include acceptance factors at this stage. Acceptance factors should also be considered in later design efforts, but they become less and less critical as task design is approached. Acceptance considerations can have other effects besides those on system effectiveness. For example, the acceptance, or more correctly, non acceptance of flight deck concepts and equipment by the SST crew can also present a serious economic problem. If costly equipment is designed and installed on SST but is not used (or at least not used effectively) it is certainly a waste of money. It should be stressed again that responsibility, authority, and acceptance considerations related to potential crew roles must be considered in the context of specific systems.

The composition and qualification of the crew in any system is a problem as complex as many of the engineering problems associated with a system design. Final decisions concerning the crew will undoubtedly have to be based on empirical as well as analytical research results. However, at this stage, it is not unreasonable to develop initial considerations concerning crew composition, size, and qualifications. Finally, as part of this effort, it is also reasonable to consider initial crew compartment concepts, or as in the case of the SST, flight deck concepts. These considerations may definitely influence potential crew roles as well as the number and qualifications of crew members.

EFFORT NO. 6, DEVELOPMENT OF PERFORMANCE ACTIVITIES

DISCUSSION OF THE SST STUDY EFFORT

A set of SST performance activities was developed to "interrogate" the flight profile phases as an aid in deriving functions, and to organize the functions on the function-flow logic diagram developed in Effort 7. In the first case an extensive list of activities was used to maximize the probability of being inclusive. The first list of activity classes derived for SST is shown in Table 1. For the second case, an attempt was made to reduce the number of activities to 6 to 10 mutually exclusive activity classes. The final list of activity classes is shown in Table 2.

DISCUSSION OF A GENERAL STUDY EFFORT

Activity classes comprise broadly defined activities which can occur during system operation and maintenance. These classes are used to derive operational and maintenance functions and therefore must include all types of performance required of operator and maintenance personnel in manning the system. However, the activity classes

SUMMARY OF EFFORT NO. 6

SST STUDY APPROACH	A GENERAL CREW REQUIREMENTS STUDY
EFFORT NO. 6. Development of Performance Activities	EFFORT NO. 6. Development of Performance Activities
INPUTS: 1. System requirements and constraints 2. Physical and functional requirements and constraints 3. Flight profiles OUTPUTS: 1. SST operational performance activities METHOD SUMMARY: 1. Develop major operational activities for crew roles 2. Develop SST principal performance activities for function derivation	INPUTS: 1. System requirements and constraints 2. Subsystem, functional, and interface requirements and constraints 3. Mission profiles OUTPUTS: 1. System performance activities METHOD SUMMARY: 1. Develop major activity classes for potential crew roles 2. Develop system performance activities for function derivation

Table 1. Initial List of SST Performance Activities.

1. Pre-flight Planning
2. Ground Control
3. Flight Control

    Attitude, Direction, Altitude, R-of-C, Airspeed

4. Configuration Control
5. Navigation
6. Flight Planning
7. Communication
8. Record Keeping
9. Passenger Accommodation
10. Power Plant Operations
11. Fuel Management
12. Electrical Power Operations
13. Hydraulic Power Operations
14. Pneumatic Power Operations
15. Environmental Control

    Lighting, Air Conditioning, Pressurization, Radiation

16. Meteorological Compensation

    Weather avoidance, Weather protection

17. Traffic Vigilance
18. Procedure Verification
19. Post Flight Debriefing

Table 2. Final List of SST Performance Activities

1.	Flight Management
2.	Phase Oriented System Checks
3.	Communication
4.	Power Plant Operation
5.	Flight Control
6.	Inlet Nozzle Configuration
7.	Navigation

Table 3. General Activity Classes.

Operations

1. Communication
   A. Air-Ground
   B. Intra-Facility
   C. Inter-Facility

2. Control
   A. Continuous
   B. Intermittent
   C. Independent

3. Monitor
   A. Active
   B. Semi-Active
   C. Passive

4. Handling
   A. Transport
   B. Storage

5. Decision Making
   A. Doctrinal
   B. Selection among alternatives
   C. Judgment

6. Discriminations
   A. Recognition
   B. Identification
   C. Comparison

Maintenance

1. Recognition of Maintenance Need
   A. Scheduled
   B. Operator Reports
   C. Malfunction Indicator

Table 3. General Activity Classes. (Concluded)

<u>Maintenance, (Continued)</u>
2. <u>Isolation of Unit Requiring Maintenance</u> A. Troubleshooting B. Automatic Checkout
3. <u>Resolution (maintenance action)</u> A. Repair B. Replace C. Align or adjust D. Service
4. <u>Inspect and Check</u>
5. <u>Supervise, Coordinate, and Control</u>

used need not be mutually exclusive. Of course, activity classes have to be related to the specific system under development, but a general example is presented in Table 3.

EFFORT NO. 7, DERIVATION OF SYSTEM FUNCTIONS

DISCUSSION OF THE SST STUDY EFFORT

The approach used to derive SST functions was essentially the same as the general study approach discussed next. The reader is referred therefore to the following discussion for the SST study as well as the general case.

DISCUSSION OF A GENERAL STUDY EFFORT

Analytical techniques used to derive functions are diverse and perhaps specific to the individual doing the analysis. A detailed discussion of various functions analysis techniques is well beyond the scope of this study effort. Serendipity Associates uses a technique which results in a function-flow logic diagram like the one presented in Ref. 3 for the SST study program. A simple example is shown as Fig. 8. This analytical technique is described in papers written by Serendipity staff members Price,[1] and Inaba.[2] In essence, the technique results in the delineation of all system functions in parametric or performance terms such that each function is bounded by an input state and an output state. Relationships between functions are also described by the paths or distribution of these input and output states between functions. As was previously stated, the technique yields a function-flow logic diagram which usually expresses information flow, although in the general case it could also represent energy or material flow.

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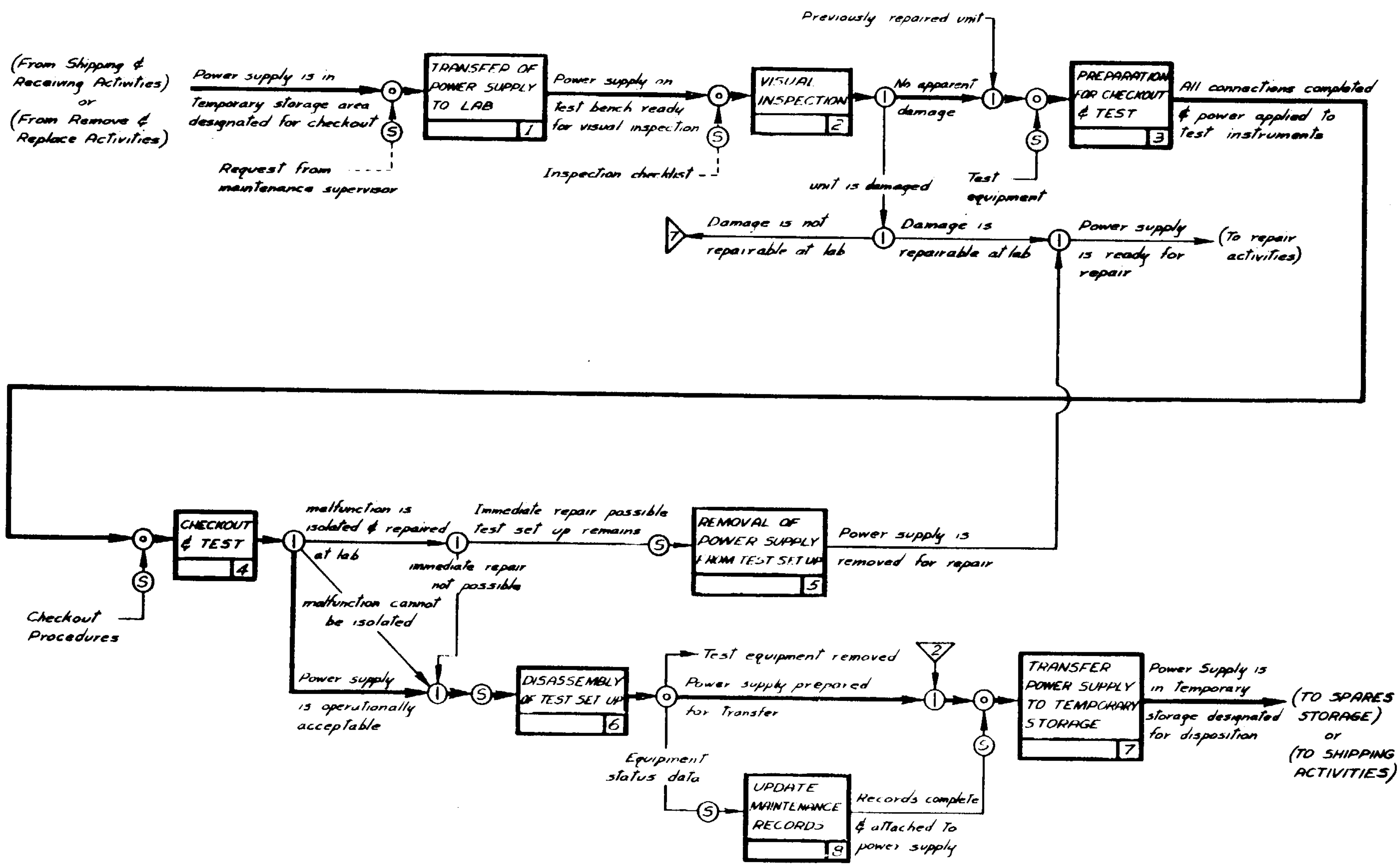
[1] Price, H. E., Criteria and Guidelines for Developing Work Analysis Diagrams: An Informal Technical Paper.

[2] Inaba, Kay, Development of Man-Machine Systems: Some Concepts and Guidelines.

FIG. 8. PRINCIPAL ACTIVITIES FOR LAB CHECKOUT OF A POWER SUPPLY
(A hypothetical example)



SUMMARY OF EFFORT NO. 7

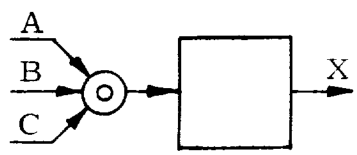
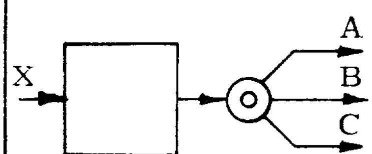
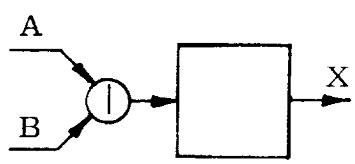
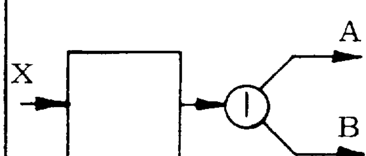
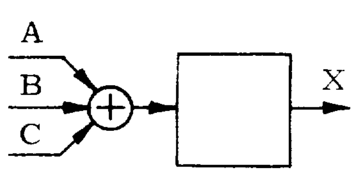
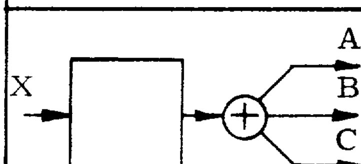
SST STUDY APPROACH	A GENERAL CREW REQUIREMENTS STUDY
EFFORT NO. 7. Derivation of SST Functions	EFFORT NO. 7. Derivation of System Functions
INPUTS: 1. SST operational performance activities 2. Flight profiles OUTPUTS: 1. Function-flow logic diagram of SST operational functions METHOD SUMMARY: 1. Select a multiplicative activity for the primary or "building" activity (flight management) 2. Derive functions for each flight phase 3. Select another activity and derive functions for each flight phase 4. Derive interactions between functions 5. Derive independent functions 6. Develop function-flow logic diagram	INPUTS: 1. System performance activities 2. Mission profiles OUTPUTS: 1. Function-flow logic diagram of operational system functions METHOD SUMMARY: 1. Select a multiplicative activity for the primary or "building" activity 2. Derive functions for each mission phase 3. Select another activity and derive functions for each mission phase 4. Derive interactions between functions 5. Derive independent functions 6. Develop function-flow logic diagram

The first step in the analytical technique is to select an activity (developed in Effort 6) which is a primary or "multiplicative" activity of the system under consideration. Multiplicative, as used here, refers to an activity which must be successfully implemented if the primary goals or output of the total system are to be met. Expressing this another way, if any primary activity (or any function, a part of that activity) is not performed, then the probability of the final system output occurring is zero, or at least approaches zero.

The primary activity is then used to interrogate each phase of the mission profile (or flight profile in the case of SST) to derive specific functions of that activity for each mission phase. In effect, this is a technique for successively partitioning an activity into smaller units of performance associated with each mission phase. Derivation of functions within an activity may be enhanced by the advance selection of critical performance, environmental, or other system parameters, which can be analyzed to determine whether their status changed during the mission phase. A change of state in any of these critical parameters would delineate a function. A function defined in this fashion, (i. e., by its input and output states) represents some kind of performance which is necessary to effect the change from input to output state, and is expressed in purely performance terms rather than means terms. In other words, functions can be delineated in terms of what must be done rather than how it must be done.

The process of deriving functions is continued for all activities through all mission phases until all the parent functions have been derived. All the functions may then be combined in a function-flow diagram by literally connecting the input states and output states of all functions, and using logic symbols to show the dependencies, contingencies, alternatives, and interactions between functions. The logic symbols used by Serendipity Associates are shown in Table 4. Functions are generally laid out on the flow-logic diagram in chronological order, from left to right, although no real time base is imposed.

Table 4. Distribution Symbols - Their Use & Meaning

Symbol	Use	Meaning
"and" ⊙		A, B, and C are all necessary to obtain X
		When X is present A, B, and C should result
"either/or" ⦶		Either A or B (but not both) can result in X
		The presence of X results in a or B (but not both)
"any or all" ⊕		A, B, C, AB, BC, AC, or ABC will result in X
		When X is present A, B, C, AB, BC, AC or ABC may result

EFFORT NO. 8, DEVELOPMENT OF CREW WORKLOAD MEASURES

DISCUSSION OF THE SST STUDY EFFORT

In order to assess crew workload, some measure of crew participation was needed because (1) every operation in which a crew member participates may not require his total attention, and (2) each human being has only a given capacity which can be employed in a performance situation. Rather than using an arbitrary rating scale, it was decided that the opinions of current jet crew members concerning the workload associated with tasks they perform would have greater reliability and validity. Validity of these data was based on the supposition that if a man believed a certain type of task required all his attention or capacity, then for all practical purposes, he was completely loaded. A performance restrictiveness scale was developed as the measure of workload. Five degrees of restrictiveness were chosen as follows:

1. Non-restrictive
2. Lightly-restrictive
3. Moderately restrictive
4. Severely restrictive
5. Completely restrictive

Next, two questionnaires were prepared for pilots and navigators which itemized certain tasks performed in current jet operations. Recipients were asked to rate the restrictiveness of each task. Time-to-perform data were also requested where appropriate. Questionnaires were administered both by mail and in person. A sample cover letter, the two questionnaires and their accompanying instructions are presented on the following nine pages. Approximately 100 pilot questionnaires were distributed with a usable return of 32; approximately 70 navigation questionnaires were distributed with a usable return of 37.

serendipity associates
9760 COZYCROFT, CHATSWORTH, CALIFORNIA / 341-0033

Dear Pilot:

Serendipity Associates is under contract to the National Aeronautics and Space Administration to study the Operational Crew Task Requirements of Supersonic Transports (SST). At this time we are concerned with "workload" and interested in Pilot opinion as to the restrictiveness of some of the tasks found in today's commercial jet operations. This will assist us in evaluating potential crew workload in the SST.

Calling upon your experience, to obtain the necessary information, we have developed a short questionnaire to elicit the necessary information. We would appreciate very much your filling out the enclosed questionnaire and returning it in the self addressed stamped envelope as soon as possible.

We have been working with the ALPA in the United States and the IFALPA also, as well as with many of the airlines. Their help and yours is very important to us as we are very concerned with the opinions of personnel who may ultimately fly the SST.

Thank you for your cooperation.

Sincerely,

Harold E. Price
Principal Investigator
SST Crew Requirements Program

HEP:dg

Encl.

Directions for filling out Questionnaire

Please fill out personal information at the top of page one. (Your name is for reference only and will not be used.)

Down the page at the left of the questionnaire is a partial list of tasks performed in the cockpit of the aircraft. To the right of these tasks are six columns. The first column reads "Task Performance not applicable (any reason)". If performance of the task is not your concern then put a check in that column and go on to the next task.

If you do perform the task we would simply like you to rate the task as to restrictiveness. By restrictiveness we mean the degree of attention the task requires of a pilot, thereby restricting his performing any other of his tasks at the same time. For example, pushing an ON-OFF switch to turn on some lights may not restrict you from monitoring a display and consequently would not be very restrictive. On the other hand, looking through the aircraft windscreen to try and locate the runway lights while breaking out at 200 feet may be considered very restrictive since your degree of attention may restrict you from performing any other task at the same time.

We have listed five degrees of restrictiveness. The choices (degrees) are: (1) non-restrictive, (2) lightly restrictive, (3) moderately restrictive, (4) severely restrictive and (5) completely restrictive. If the performance of the task you are rating does not preclude your performing other pilot tasks you would put a check in the "non-restrictive" column. If performing the task requires such a degree of attention on your part as to restrict you from performing any other task simultaneously then you would check the "completely restrictive" column. If a task doesn't fall into either of those categories but is somewhere in between you would check one of the three remaining restrictiveness columns.

Finally, when applicable we would like to know the average time it takes to perform the task one time under normal conditions. Note this time at the far right in the space provided.

We realize that there may still be questions in your mind as to filling out this questionnaire. It may help to follow these rules:

1. All the tasks are performed under instrument conditions.
2. When you rate task restrictiveness remember that we are not concerned with your ability to perform emergency or non-routine tasks but only other routine pilot tasks.
3. Where a task may vary in restrictiveness as to airport, aircraft, etc. take the average condition. For example, flying a standard instrument departure at a certain airport may be so complex because of the airport's peculiar procedures or locale, as to make the task much more restrictive than normally. We are not concerned with this unique situation but only the typical situation.

Name ____________ Airline ____________

Equipment you are currently flying ____________

Usual Flight Position: Captain ________ 1st Officer ________

Approximate Total Airline Hours ________ Jet Hours ________

Presently flying Domestic ________ International ________ route.

ALL THE FOLLOWING TASKS ARE PERFORMED UNDER INSTRUMENT CONDITIONS:

Task	Task Performance Not Applicable (Any reason)	TASK RESTRICTIVENESS: Non-Restrictive	Lightly Restrictive	Moderately Restrictive	Severely Restrictive	Completely Restrictive	Time Estimated in Minutes and Seconds
1. Predict fuel over destination.							
2. Verify ETA validity.							
3. Receive, copy and verify ATC clearances or revisions.							
4. Intercom announcement.							
5. Calculate wind velocity and relative bearing.							
6. Calculate drift and ground speed.							
7. Evaluate aircraft speed vs. runway remaining on take-off for take-off/abort decision.							
8. Fly one minute holding pattern without use of autopilot.							
9. Fly one minute holding pattern using autopilot COURSE-HOLD.							
10. Fly a standard instrument departure manually.							
11. Fly a standard instrument departure using autopilot COURSE-HOLD.							
12. Fly standard instrument approach manually.							
13. Fly standard instrument approach using autopilot COURSE-HOLD.							
14. Fly ILS final approach manually.							

ALL THE FOLLOWING TASKS ARE <u>PERFORMED UNDER</u>

<u>INSTRUMENT CONDITIONS</u>:

	Task Performance Not Applicable (Any reason)	TASK RESTRICTIVENESS: Non-Restrictive	Lightly Restrictive	Moderately Restrictive	Severely Restrictive	Completely Restrictive	Time Estimate in Minutes and Seconds
15. Fly ILS Final approach using autopilot coupler.							
16. Maintain runway centerline and wings level attitude during take-off roll.							
17. Perform pre-descent check.							
18. Reconfigure aircraft for landing (flaps, spoilers, gear, etc.).							
19. Maintain constant MACH cruise speed.							
20. Monitor engine performance instruments during take-off.							
21. Verify VOR station identification.							
22. Maintain cognizance of enroute weather conditions via all cockpit instrumentation (radar, temperature gauges, etc.).							
23. Vectoring aircraft through storm, using airborne weather radar.							
24. Monitor communications to other aircraft in terminal area.							
25. Monitor autopilot operation at cruise.							
26. Maintain altitude control in moderate to severe turbulence.							
27. Maintain obstruction and other traffic clearance from parking area to operational runway.							

Directions For Filling Out Questionnaire

Please fill out personal information at the top of page one. (Your name is for reference only and will not be used.)

Down the page at the left of the questionnaire is a partial list of navigation type tasks performed on the flight deck of the aircraft. The first column across the top reads "Task Performance Not Applicable (any reason)". If performance of the task is not your concern then put a check in that column and go on to the next task.

If you do perform the task we would like you to name the general type of equipment which you are using in the performance of this task and check in the appropriate column whether your performance of that task is completely manual, partially automated, or performed completely automatically by the equipment.

Next we would like you to rate the task as to restrictiveness. By restrictiveness we mean the degree of attention the task requires, thereby restricting the operator from performing any other of his tasks at the same time. For example, pushing an ON-OFF switch to turn on some lights may not restrict you from monitoring a display and consequently would not be very restrictive. On the other hand, converting a plotted point representing a fix of the aircraft's position into exact geographical coordinates may be considered very restrictive since your degree of attention may restrict you from performing any other task at the same time.

We have listed five degrees of restrictiveness. The choices (degrees) are: (1) non-restrictive, (2) lightly restrictive, (3) moderately restrictive, (4) severely restrictive and (5) completely restrictive. If the performance of the task you are rating does not preclude your performing other routine tasks you would put a check in the "non-restrictive" column. If performing the task requires such a degree of attention on your part as to restrict you from performing any other task simultaneously then you would check the "completely restrictive" column. If a task doesn't fall into either of those categories but is somewhere in between you would check one of the three remaining restrictiveness columns.

Finally, when applicable we would like to know the average time it takes to perform the task one time under normal conditions. Note this time at the far right in the space provided.

We realize that there may still be questions in your mind as to filling out this questionnaire. It may help to follow these rules:

1. All the tasks are performed under instrument conditions.

2. When you rate task restrictiveness remember that we are not concerned with your ability to perform emergency or non-routine tasks but only other routine navigation tasks.

3. Where a task may vary in restrictiveness as to airport, ground aids, aircraft, etc. take the average condition. We are not concerned with the unique situation but only the typical situation.

Name ______________ Airline ______________

Equipment you are currently flying ______________

Approximate Total Airline Hours ________ Jet Hours ________

Presently flying Domestic ________ International ________ route.

Flight Position: Pilot Navigator ______ Specialist Navigator ______

ALL THE FOLLOWING TASKS ARE PERFORMED UNDER INSTRUMENT CONDITIONS:

			MEANS FOR PERFORMING TASKS			TASK RESTRICTIVENESS					
	Task Performance Not Applicable (Any Reason)	General Type of Equipment Provided	Completely Manual	Partly Automated	Completely Automated	Non-Restrictive	Lightly Restrictive	Moderately Restrictive	Severely Restrictive	Completely Restrictive	Time Estimate in Minutes and Seconds
1. Obtain position fix by means of standard hyperbolic system.											
2. Obtain position fix by means of celestial techniques.											
3. Perform airborne gyro compass alignment check via celestial techniques.											
4. Unslave gyro compass and align for "free gyro mode" operation.											
5. Obtain position fix by means of short range point-source system.											
6. Verify the validity of the destination ETA.											
7. Calculate wind velocity and relative bearing.											
8. Calculate drift and ground speed.											
9. Pre-set and reset destination coordinates in self-contained navigation system.											
10. Determine course to steer.											
11. Maintain geographic plot of navigational situation.											
12. Calculate initial point of turn to minimize cross track error following turn.											

ALL THE FOLLOWING TASKS ARE PERFORMED UNDER INSTRUMENT CONDITIONS:

		MEANS FOR PERFORMING TASKS				TASK RESTRICTIVENESS					
	Task Performance Not Applicable (Any Reason)	General Type of Equipment Provided	Completely Manual	Partly Automated	Completely Automated	Non-Restrictive	Lightly Restrictive	Moderately Restrictive	Severely Restrictive	Completely Restrictive	Time Estimate in Minutes and Seconds
13. Derive navigational data to modify flight plan for storm avoidance.											
14. Predict fuel over destination.											
15. Derive doppler bias error											
16. Maintain cognizance of enroute weather conditions via all cockpit instrumentation.											
17. Determine self-combined navigation system accuracy following a maneuver requiring "memory" operation.											

SUMMARY OF EFFORT NO. 8

SST STUDY APPROACH	A GENERAL CREW REQUIREMENTS STUDY
EFFORT NO. 8. Development of Crew Workload Measures	EFFORT NO. 8. Development of Crew Workload Measures
INPUTS: 1. Function-flow logic diagram of SST operational functions 2. Current jet workload data	INPUTS: 1. Function-flow diagram of operational system functions 2. Equivalent task restrictiveness ratings
OUTPUTS: 1. Crew workload measurement scale	OUTPUTS: 1. Crew workload measurement scale
METHOD SUMMARY: 1. Develop a performance restrictiveness scale 2. Develop a questionnaire for current jet tasks restrictiveness ratings 3. Administer questionnaire 4. Analyze data 5. Develop a composite-workload scale	METHOD SUMMARY: 1. Develop a performance restrictiveness scale 2. Develop criteria for rating functions relative to the restrictiveness scale OR 3. Develop equivalent task ratings from empirical or field research data 4. Develop a composite workload measure

The tabulated results are contained in Table 4 which is the composite workload scale.

DISCUSSION OF A GENERAL STUDY EFFORT

The development of crew workload measures necessitates the use of a performance restrictiveness scale in a general approach just as in the method used for the SST. The same scale used for the SST should be appropriate for the general case. This is a five-point scale as follows:

1. Non-restrictive
2. Lightly restrictive
3. Moderately restrictive
4. Severely restrictive
5. Completely restrictive

The definition of restrictiveness may be clarified by an excerpt from the SST questionnaire as follows:

> By restrictiveness we mean the degree of attention the task requires of a pilot, thereby restricting his performing any other of his tasks at the same time. For example, pushing an ON-OFF switch to turn on some lights may not restrict you from monitoring a display and consequently would not be very restrictive. On the other hand, looking through the aircraft windscreen to try and locate the runway lights while breaking out at 200 feet may be considered very restrictive since your degree of attention may restrict you from performing any other task at the same time.

Next, it is necessary to develop criteria for rating functions relative to the restrictiveness scale; or as was done for the SST study, equivalent task ratings may be developed from empirical or field research data. The authors are not familiar with any effective criteria

Task No.		$\overline{R}$	No. D. P.	Range Min.	Max.	$\overline{T}$	No. D. P.	Range Min.	Max.
P1.	Predict fuel over destination.	2.29	31	1	5	1'15"	30	0.16	3
P2.	Verify ETA validity.	2.18	31	1	4	1'04"	29	0.05	3
P3.	Receive, copy and verify ATC clearances or revisions.	3.17	30	1	5	1'04"	28	0.25	3
P4.	Intercom announcement.	2.72	32	1	5	1'15"	26	0.033	3
P5.	Claculate wind velocity and relative bearing.	2.82	30	1	5	1'12"	27	0.25	4
P6.	Calculate drift and ground speed.	2.03	30	1	5	1'11"	28	0.033	4
P7.	Evaluate aircraft speed vs. runway remaining on take-off for take-off/abort decision.	2.45	29	1	5	Ø'14"	19	0.016	1
P8.	Fly one minute holding pattern without use of autopilot.	2.81	32	1	5	3'40"	13	1	4.5
P9.	Fly one minute holding pattern using autopilot COURSE-HOLD.	2.25	32	1	3	3'38"	12	1	4.5
P10.	Fly a standard instrument departure manually.	2.84	32	1	4	5'22"	11	3	10
P11.	Fly a standard instrument departure using autopilot COURSE-HOLD.	2.52	31	1	4	5'24"	10	3	10
P12.	Fly standard instrument approach manually.	3.44	32	1	5	5'05"	18	2	10
P13.	Fly standard instrument approacn using auto-pilot COURSE-HOLD.	3.06	32	1	5	5'05"	13	2	10
P14.	Fly ILS final approach manually.	3.59	32	1	5	3'32"	13	2	5
P15.	Fly ILS final approach using autopilot coupler.	3.19	32	1	5	3'45"	12	2	5
P16.	Maintain runway centerline and wings level attitude during take-off roll.	3.19	32	1	5	Ø'50"	12	0.5	1.5
P17.	Perform pre-descent check.	2.27	30	1	5	Ø'35"	19	0.16	1.5
P18.	Reconfigure aircraft for landing (flaps, spoilers, gear, etc.)	2.23	31	1	4	1'01"	13	0.05	4
P19.	Maintain constant MACH cruise speed.	1.70	30	1	4	Ø'24"	*5	0.08	1
P20.	Monitor engine performance instruments during take-off.	2.55	29	1	5	Ø'38"	11	0.05	1
P21.	Verify VOR station identification.	2.13	31	1	5	Ø'16"	18	0.05	0.5
P22.	Maintain cognizance of enroute weather conditions via all cockpit instrumentation (radar, temperature guages, etc.)	2.19	31	1	4	Ø'49"	6	0.05	2
P23.	Vectoring aircraft through storm, using airborne weather radar.	3.30	30	1	5	4'28"	*6	0.25	10
P24.	Monitor communications to other aircraft in terminal area.	2.63	32	1	4	2'47"	*4	0.16	10
P25.	Monitor autopilot operation at cruise.	1.47	32	1	2	2'08"	*5	0.033	10
P26.	Maintain altitude control in moderate to severe turbulence.	3.87	31	2	5	4'08"	*4	0.5	10
P27.	Maintain obstruction and other traffic clearance from parking area to operational runway.	2.91	32	1	5	3'53"	*8	1	5
N1.	Obtain position fix by means of standard hyperbolic system.	3.94	33	2	5	2'36"	30	0.5	5
N2.	Obtain position fix by means of celestial techniques.	4.45	38	2	5	11'01"	35	5	18
N3.	Perform airborne compass alignment check via celestial techniques.	3.95	38	2	5	2'43"	35	0.5	10
N4.	Unslave gyro compass and align for "free gyro mode" operation.	3.67	31	1	5	2'26"	26	0.12	8
N5.	Obtain position fix by means of short range point-source system.	2.75	32	1	5	1'47"	32	0.25	12
N6.	Verify the validity of the destination ETA.	3.16	32	1	5	1'44"	32	0.33	11
N7.	Calculate wind velocity and relative bearing.	3.24	37	1	5	2'34"	33	0.33	30
N8.	Calculate drift and ground speed.	2.76	37	1	5	1'46"	27	0.33	11
N9.	Pre-set and reset destination coordinates in self-contained navigation system.	3.60	*5	2	5	Ø'58"	*5	0.33	2
N10.	Determine course to steer.	3.22	37	1	5	1'30"	32	0.25	10
N11.	Maintain geographic plot of navigational situation.	3.24	37	1	5	1'30"	32	0.16	11
N12.	Calculate initial point of turn to minimize cross track error following turn.	3.30	26	1	5	1'20"	22	0.25	3
N13.	Derive navigational data to modify flight plan for storm avoidance.	3.30	26	1	5	2'36"	18	0.16	6
N14.	Predict fuel over destination.	3.00	22	1	5	1'57"	21	0.5	8
N15.	Derive doppler bias error.	3.00	10	1	5	2'02"	10	0.5	4
N16.	Maintain cognizance of enroute weather conditions via all cockpit instrumentation.	2.13	23	1	3	1'52"	15	0.5	5
N17.	Determine self-combined navigation system accuracy following a maneuver requiring memory operation.	3.57	*7	1	5	2'26"	*7	0.25	6.25

*Minimal Data

Table 4. Current Jet Tasks and Restrictiveness Values for Workload Scaling.

for rating task (or function) restrictiveness and do not recommend this technique over the use of field or empirical data as in the SST study. A technique for gathering field research data similar to that in the SST approach is satisfactory--if a representative user group is accessible. In using this technique, however, it is important to derive the task descriptions to be rated from operations of the system in which the field personnel (those receiving the questionnaire) are participating, not from the system under development. In other words, a jet pilot should rate the restrictiveness of the tasks he performs and should not be asked to estimate the restrictiveness of SST tasks he has never performed. However, the task descriptions used should approximate the skill and knowledge requirements expected for the system under development.

Recently, several investigators have attempted to develop quantitative approaches to workload investigation. Perhaps the most prominent of these methods was developed by Senders, Lindquist, and Gross,[1] based on an information theory. Siegel and Wolf[2] have developed a computer-based technique wherein data concerning performance by average operators constitutes part of the input data. Since these two methods, and many more are discussed and summarized in reference 9, no attempt to review any specific method will be made here. It is sufficient to say that any approach which results in valid quantitative workload values developed from field or empirical research efforts is preferable to merely estimating workload values. In any event, a composite workload scale must be developed to apply to functions in Effort 11.

[1] Lindquist, O. H., and Gross, R. L. (Minneapolis-Honeywell Regulator Co.). Human engineering man-machine study of a weapon system. Minn. Honeywell Regulator Co. Rep., 1958, No. R-ED 6094.

[2] Siegel, A. I., and Wolf, J. J. (Applied Psychological Services). A Technique for evaluating man-machine system designs. Human Factors, 1961, 3, 18-28.

EFFORT NO. 9, DEVELOPMENT OF A FUNCTION-TIMELINE

DISCUSSION OF THE SST STUDY EFFORT

Development of a function-timeline for the SST was based on a nominal flight time of 150 minutes determined during development of the flight profile (Effort 3). Further, it was determined that performance time data for the SST functions could not be estimated or obtained for any more precise time units than minutes. Therefore, the timeline base was laid out in one minute intervals.

The performance time for each function was estimated from performance times for similar functions in current jet operations (some of this data was obtained from our questionnaires, Effort 8) or deduced from logical application of requirements and constraints related to a particular function. For example, some functions are performed in the shortest time possible (e. g. , phase-oriented system checks). Other function performance times are governed by regulation or system characteristics (e. g. , flight control). Because of this difference, it was found useful to consider each function relative to one of the following four classifications:

1. Continuous functions require some amount of attention over a continuous period of time (e. g. , attitude control).

2. Intermittent functions require the same tasks more than once during a mission or flight (e. g. , position reporting).

3. Phase discrete functions are those associated with a particular phase or point of the flight profile (e. g. , lower landing gear).

SUMMARY OF EFFORT NO. 9

SST STUDY APPROACH	A GENERAL CREW REQUIREMENTS STUDY
EFFORT NO.9. Development of Function-time Line	EFFORT NO. 9. Development of Function-time Line
INPUTS: 1. Flight profiles 2. SST operational functions OUTPUTS: 1. SST function-time line METHOD SUMMARY: 1. Determine a reasonable real-time scale unit 2. Estimate and plot performance times for each function against real-time scale	INPUTS: 1. Mission profiles 2. Operational system functions Outputs: 1. Operational function-time line METHOD SUMMARY: 1. Determine a reasonable real-time scale unit 2. Estimate and plot performance times for each function against real-time scale OR 3. Obtain equivalent task performance time ratings from empirical or research data and plot times for each function against real-time scale

4. <u>Independent functions</u> allow considerable occurrence latitude (e. g., update log book).

A function-timeline was then prepared by plotting the duration of each function against the real-time base. Continuous functions were plotted as a continuous line from beginning to end. Intermittent functions were plotted each time they occurred and a performance time indicated for each occurrence. The functions were ordered within their respective activity groups on the chart.

DISCUSSION OF A GENERAL STUDY EFFORT

Development of function-timeline plots is a standard procedure in which mission functions are plotted against a real-time base. Reference 6 discusses techniques for developing time ordered plots in some detail. Figure 9 presents an example from reference 6 showing mission subsystem control events plotted against a time base.

The general approach is essentially the same as that discussed for the SST study effort. First, a time base must be selected. While it is important that the units of time be as small as feasible, it is not necessary that the time base be continuous. Separate function-timeline plots can be developed for different mission phases when the real-time duration of the phases is quite different. It will also be useful to specify whether system functions are continuous, intermittent, phase discrete, or independent as defined in the discussion of the SST study effort. Performance time values must be determined for each function and these functions should be plotted on the appropriate position along the real-time base. Performance time values may be estimated from experience with, or from knowledge of, similar functions in other systems; or equivalent task performance time ratings may be obtained from potential user groups operating with similar equipment; or empirical research data may be obtained. The functions should be grouped

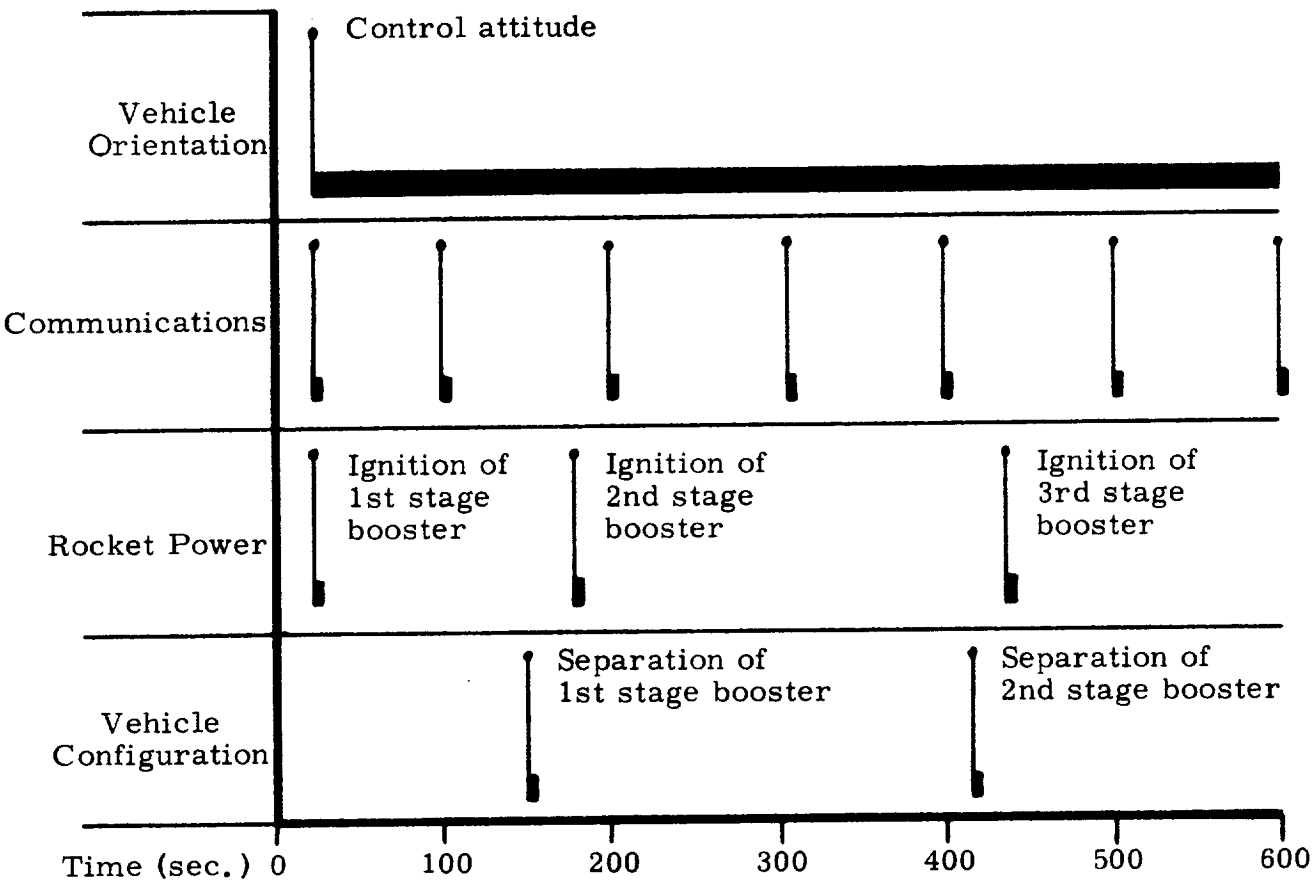


Figure 9. Mission subsystem control events (taken from ref. 6).

within their respective activity classes for presentation on the function-timeline chart.

EFFORT NO. 10, DEVELOPMENT OF ACTIVITY AND PERFORMANCE DESCRIPTIONS

DISCUSSION OF THE SST STUDY EFFORT

The principal emphasis of this effort was on the development of implementation concepts for the SST. Implementation concepts were developed with respect to both manual and automatic feasibility. Associated descriptive information was also developed in addition to the implementation concepts. Each function identified on the flow-logic diagram and each activity class to which the functions belong was described in some detail. Basically, the activity and function descriptions were the same except for the level of generality used. Six specific topics were considered in each activity and function description as follows:

1. Purpose (basic requirements and constraints)
2. Current jet operation requirements and constraints
3. Current jet implementation concepts
4. SST potential operational requirements and constraints
5. Feasible automated implementation concepts for SST
6. Feasible manual implementation concepts for SST

Chapter 2 contains a discussion of the types of information presented under each of the six topics above and the reader is referred to that chapter for further detail on this effort.

It should be emphasized that the important aspect of this effort was the development of feasible automatic and manual implementation concepts for each SST function. An extensive amount of literature was searched and many discussions were held with cognizant personnel to

SUMMARY OF EFFORT NO. 10

SST STUDY APPROACH	A GENERAL CREW REQUIREMENTS STUDY
EFFORT NO. 10. Development of Activity and Function Performance Descriptions	EFFORT NO. 10. Development of Activity and Function Performance Descriptions
INPUTS: 1. Requirements and constraints of potential crew roles 2. SST operational functions 3. Feasible design concepts for SST OUTPUTS: 1. Feasible automated and manual implementation concepts for SST activities and functions 2. Associated, useful, descriptive information METHOD SUMMARY: 1. Describe purpose of activity and function 2. Document current jet operational requirements and constraints 3. Describe current jet implementation concepts 4. Analyze potential SST operational requirements and constraints 5. Develop feasible automated implementation concepts for SST 6. Develop feasible manual implementation concepts for SST	INPUTS: 1. Requirements and constraints of potential crew roles 2. Operational system functions 3. Feasible subsystem and function design concepts OUTPUTS: 1. Feasible automated and manual implementation concepts for operational system activities and functions 2. Function associated information METHOD SUMMARY: 1. Describe purpose of activity or function 2. Describe similar or analogous system implementation concepts 3. Develop feasible automated implementation concepts 4. Develop feasible manual implementation concepts

obtain information on techniques projected to be feasible for SST. This information on techniques together with the data developed concerning potential crew roles for the SST (Effort 5) was then integrated into discussions of feasible implementation concepts for SST. These possible implementation concepts make up the majority of the technical appendices of this report.

DISCUSSION OF A GENERAL STUDY EFFORT

As in the case of the SST study effort, the primary emphasis of this effort is the development of feasible automatic and manual implementation concepts for each system function. Associated descriptive information may also be developed during this effort as the overall program requires, but the basic information which the activity and function description should contain is as follows:

1. Purpose of activity or function
2. Similar or analogous system implementation concepts
3. Feasible automated implementation concepts
4. Feasible manual implementation concepts

Purpose should describe the basic requirements and constraints of the activity or function, or the general rationale or need for the activity or function.

Similar or analogous system implementation concepts will generally be useful for comparative purposes. In many cases (as was true for the SST) state of the art techniques for implementing functions of a current family of systems are frequently similar to backup or manual techniques for implementing functions in a future system of the same family. Description of current system implementation concepts as well as implementation concepts for the system under development should include information concerning the following aspects:

1. Crew responsibility
2. Crew equipment interface
3. On line equipment
4. Off line equipment
5. Performance aids
6. Malfunction effects

Feasible automated implementation concepts and feasible manual implementation concepts should be developed in a manner similar to that just described for current system implementation concepts. It is assumed here that the user of this method is not responsible for the complete design solution, but rather, is responsible for determining concepts for crew participation in different design configurations. If this is true, then all feasible implementation techniques which are identified in the technical literature or available from cognizant design personnel should be considered. If this is not true, then the specific manner in which the crew participates in the implementation of this function for a specific design solution should be documented in some detail.

EFFORT NO. 11, DEVELOPMENT OF CREW WORKLOAD-MANNING PROFILES

DISCUSSION OF THE SST STUDY EFFORT

The crew workload-manning profiles developed for automatic and manual implementation concepts of the SST are presented in Ref. 2. A partial version of one of these profiles is shown as Figure 10. The method employed is fairly obvious in the figures. Essentially, the crew workload measurement scale developed in Effort No. 8 was applied to the implementation concept for each function. The resultant restrictiveness value determined the thickness of the lines on the plot. After restrictiveness values determined and plotted for each function, a composite profile was developed by simply adding up the restrictiveness values for each function being performed over each minute of the mission profile. Separate composite profiles were prepared for feasible automatic and manual implementation concepts.

The most difficult aspect of this effort was the assessment of the restrictiveness value of each SST function in terms of the workload measurement scale. Each implementation concept was critically reviewed in order to identify human performance requirements inherent in the concept. Then, a reasonable and logical correlate was found among those tasks listed in the measurement scale. The actual assessment of restrictiveness values for each function required specific assumptions or working rules. These are discussed in the body of the report.

It is believed that assessment of restrictiveness values with this technique although admittedly subjective, provided for:

1. Minimization of subjectiveness in weight assignments, and

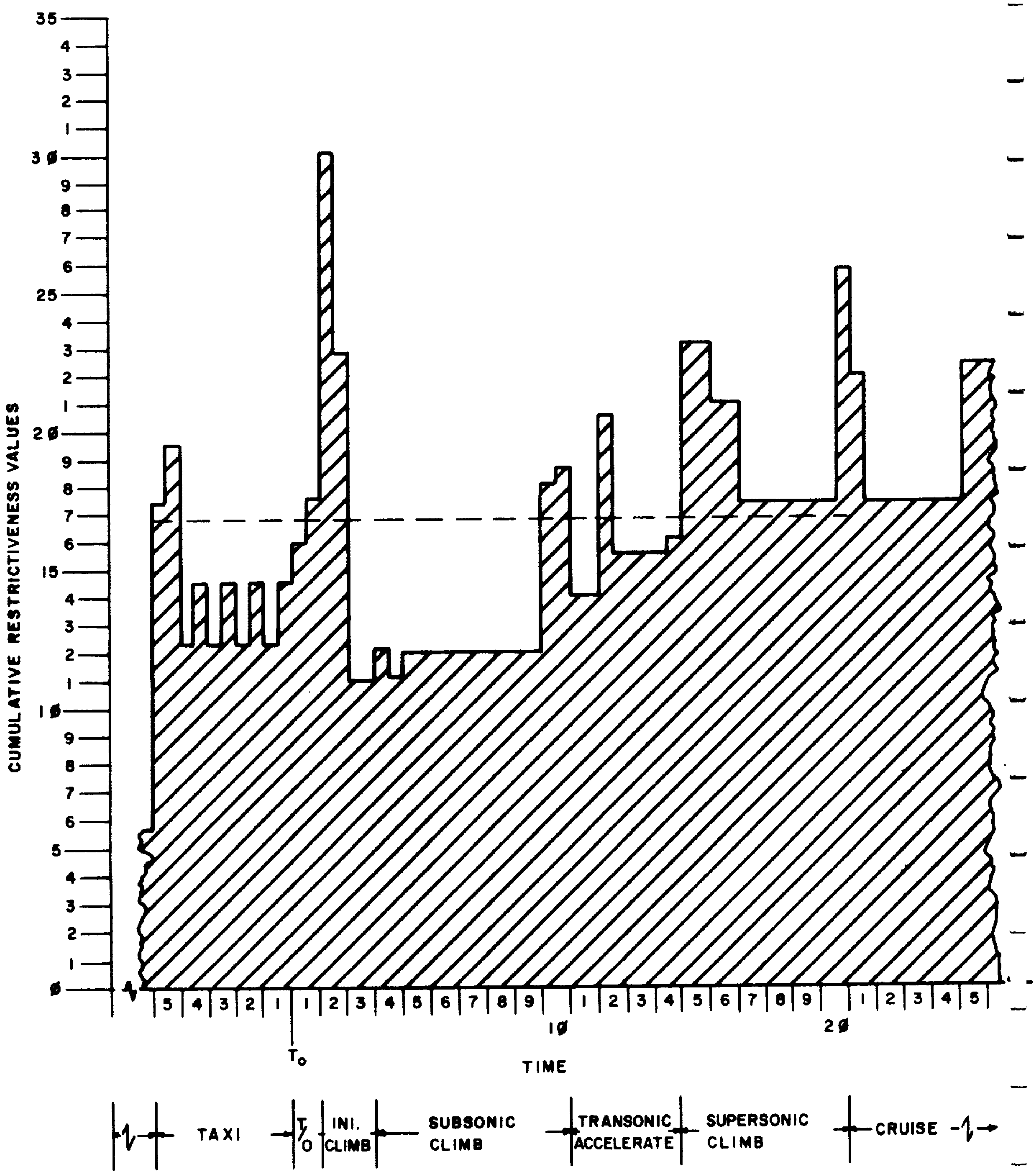


Figure 10. Partial graph of cumulative workload.

SUMMARY OF EFFORT NO. 11

SST STUDY APPROACH	A GENERAL CREW REQUIREMENTS STUDY
EFFORT NO. 11. Development of Crew Workload Manning Profile	EFFORT NO. 11. Development of Crew Workload Manning Profile
INPUTS: 1. Feasible implementation concepts for SST activities and functions 2. SST operational functions 3. SST function-time line 4. Effects of malfunctions on manning	INPUTS: 1. Feasible implementation concepts for operational system activities and functions 2. Operational system functions 3. Operational function-time line 4. Effects of malfunctions on manning
OUTPUTS: 1. Crew workload-manning profiles for automatic and manual implementation concepts	OUTPUTS: 1. Crew workload-manning profiles for automatic and manual implementation concepts
METHOD SUMMARY: 1. For each function: (a) Review the feasible automated implementation concept (b) Determine a restrictiveness value for the function by application of the crew workload measurement scale (c) Develop separate restrictiveness values for each clearly different implementation concept 2. Plot the function as a "bar" on the function-time line scale with the thickness of the bar being the restrictiveness value 3. Repeat Steps 1 and 2 for all the automatic implementation concepts	METHOD SUMMARY: 1. For each function: (a) Review the feasible automated implementation concept (b) Determine a restrictiveness value for the function by application of the crew workload measurement scale (c) Develop separate restrictiveness values for each clearly different implementation concept 2. Plot the function as a "bar" on the function-time line scale with the thickness of the bar being the restrictiveness value 3. Repeat Steps 1 and 2 for all the automatic implementation concepts

SUMMARY OF EFFORT NO. 11

SST STUDY APPROACH	A GENERAL CREW REQUIREMENTS STUDY
EFFORT NO. 11. Development of Crew Workload Manning Profile	EFFORT NO. 11. Development of Crew Workload Manning Profile
METHOD SUMMARY: (Continued) 4. Sum up the restrictiveness values for all functions over the entire real-time scale. This results in a manning profile 5. Repeat 1-4 for the manual implementation concepts	METHOD SUMMARY: (Continued) 4. Sum up the restrictiveness values for all functions over the entire real-time scale. This results in a manning profile 5. Repeat 1-4 for the manual implementation concepts

maximization of reliability and validity, by the utilization of average values obtained from experienced personnel.

2. The establishment of a numerical value which represents a measure of the referent and is in a form amenable for alteration or variation on a prescribed scale.

3. Consistency in the assignment of weight factors to SST functions with highly similar performance requirements.

There might be some concern over the reliability and validity of the restrictiveness values obtained utilizing this technique. However, at this advanced stage in the SST development, given the absence of any empirical data, we believe this technique to be practical for preliminary investigation of workloads.

DISCUSSION OF A GENERAL STUDY EFFORT

In the general case the method described for the SST study is also appropriate. Any attempts to improve the method should be directed at improving the technique for developing specific workload measures for each function. As was stated in the discussion of the SST study effort, it was necessary to subjectively correlate the tasks presented in the workload scale for current jet operations with the SST implementation concepts according to their performance similarities. A better technique would be to prepare in advance, task descriptions which are correlated with the functions of the system under development, and then to obtain restrictiveness data from representative user groups about these tasks. This would eliminate the necessity for subjective matching when the data are obtained. In any case, once restrictiveness values are established for each function, the same techniques used in the SST study can be employed in plotting these restrictiveness values and developing a cumulative crew workload-manning profile for the entire mission.

EFFORT NO. 12, MALFUNCTION ANALYSIS

DISCUSSION OF THE SST STUDY EFFORT

One of the basic objectives underlying this study was to obtain and analyze malfunction data on current commercial jet aircraft to provide:

1. A basis for estimating the effect of malfunction on crew workload.
2. A basis for indicating where problems exist in current jets and where emphasis might be placed on SST design, human engineering and training.
3. A basis for programming malfunctions in SST simulation.

The specific kinds of data used and the sources of these data are discussed in some detail in Ref. 1. In essence, data were available from the FAA concerning current jet malfunctions categorized according to the ATA 100 Series Aircraft Systems. These data were analyzed and recomputed as necessary in order to prepare bar graphs showing the number of failures of each system per thousand hours of operating time, and the distribution within subsystems of the failures for any system. Examples of these graphs are presented in Figures 11 and 12.

DISCUSSION OF A GENERAL STUDY EFFORT

Techniques similar to those described for the SST study effort can be used for the general study effort if equivalent malfunction data

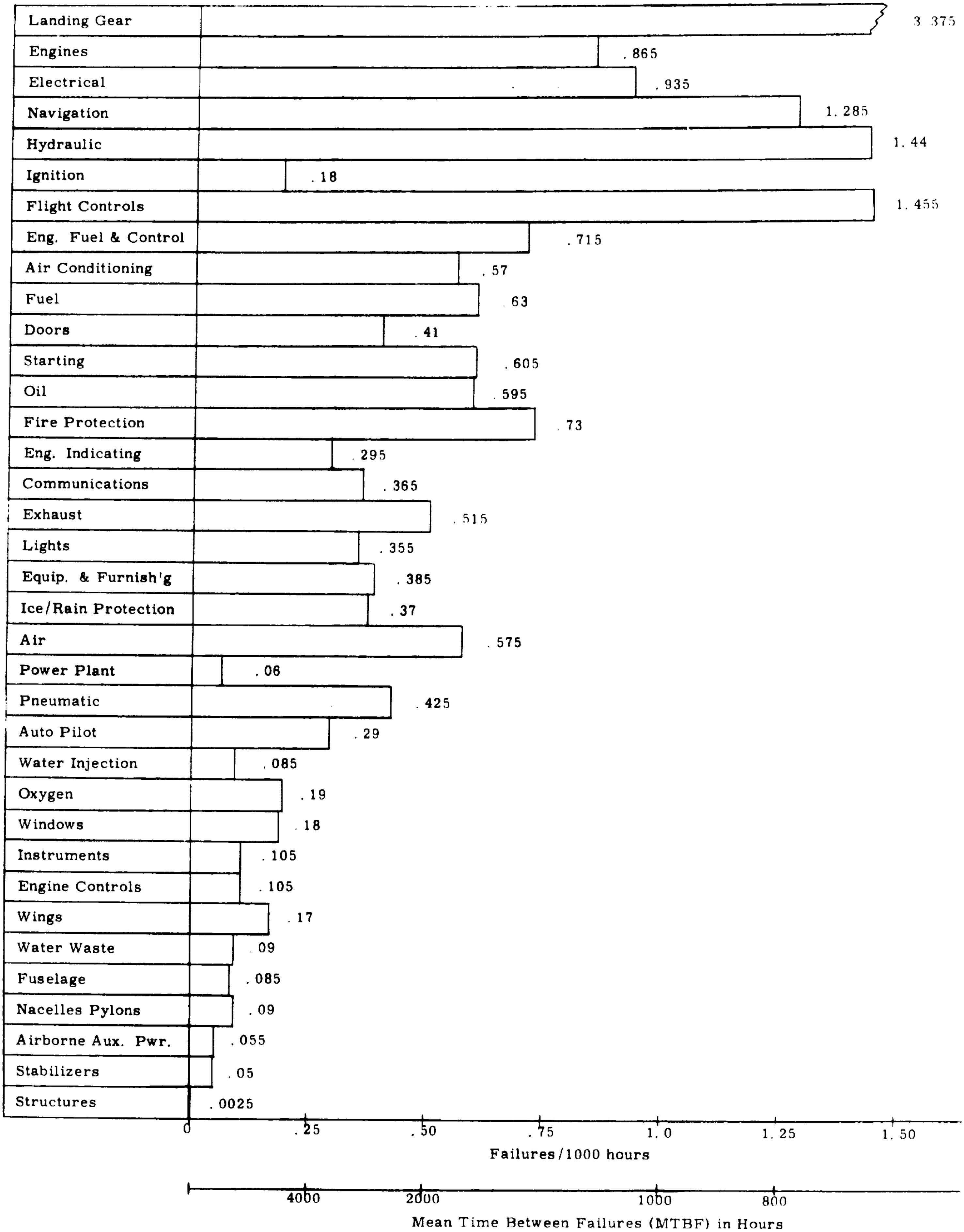
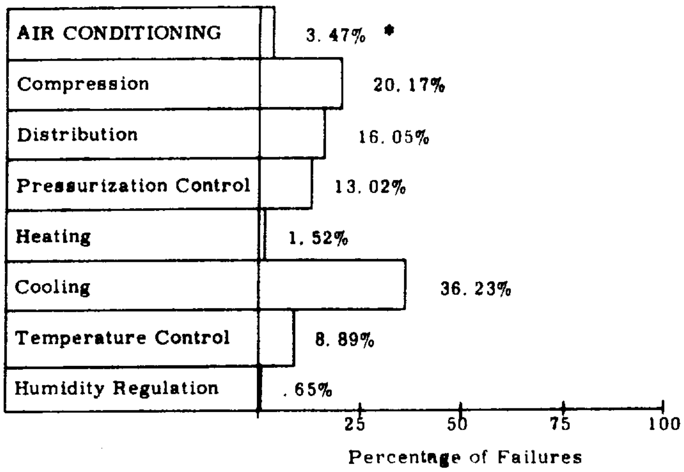
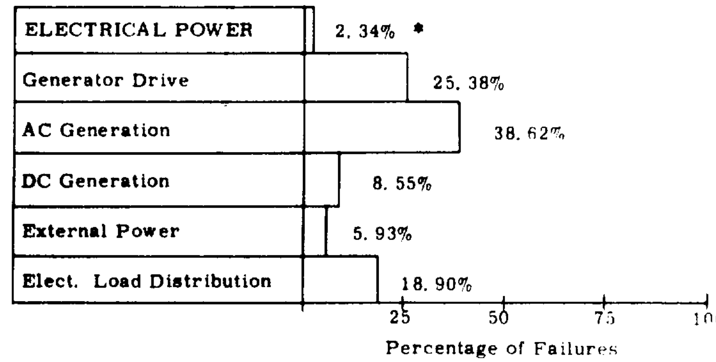


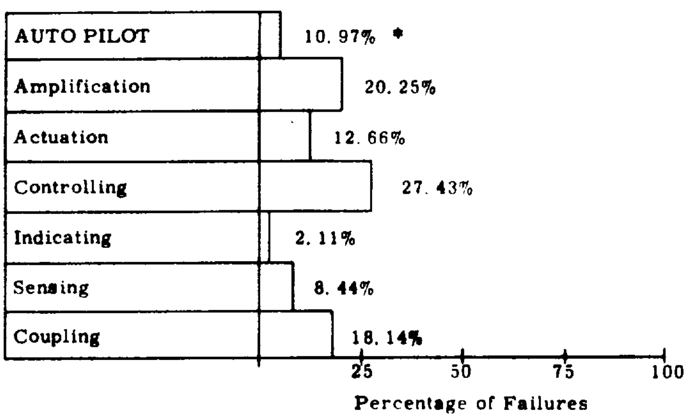
Figure 11. System failures per 1000 hours of flight.



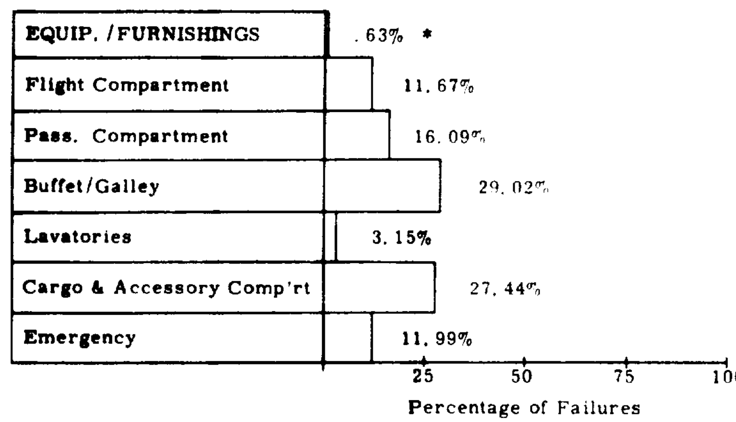
Air conditioning subsystem failures.



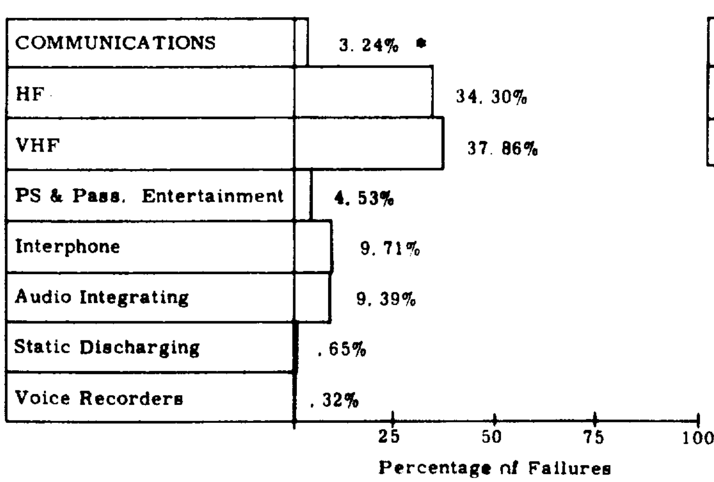
Electrical power subsystem failures.



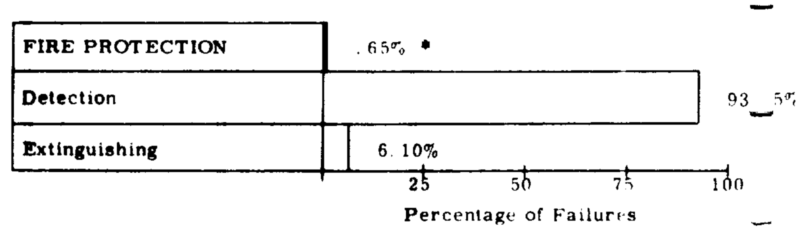
Auto pilot subsystem failures.



Equip. /furnishings subsystem failures.



Communications subsystem failures.



Fire protection subsystem failures.

* These figures indicate percentages of those failures not attributable to any particular subsystem within the system.

Figure 12. Distribution of system failures among subsystems.

SUMMARY OF EFFORT NO. 12

SST STUDY APPROACH	A GENERAL CREW REQUIREMENTS STUDY
EFFORT NO. 12. Malfunction Analysis	EFFORT NO. 12. Malfunction Analysis
INPUTS: 1. Current jet system and subsystem malfunction data OUTPUTS: 1. Frequency and distribution of malfunctions METHOD SUMMARY: 1. For the ATA 100 series aircraft systems; compute and display as a bar graph the system failures/1000 hours and system MTBF 2. Compute and display as bar graphs the percentage ratio of failures among subsystems for each ATA 100 series systems	INPUTS: 1. System reliability requirements OUTPUTS: 1. Frequency and distribution of malfunctions METHOD SUMMARY: 1. Determine the allocation of reliability to each function 2. Determine the MTBF for each function 3. Determine the probability of failure for each function during a mission

are available from a current system or family of systems corresponding to the system under development. In situations where such data are not available, the malfunction analysis effort may require knowledge of the system reliability or effectiveness requirements. These, in turn, will permit allocating reliability to each function, determining the MTBF for each function, and determining the probability of failure for each function during a mission. Since these techniques are complicated and influenced by the specific system under consideration, they are beyond the scope of this study. The desired result of this effort, however, is the same regardless of the technique used, namely, a determination of the frequency and distribution of malfunctions for all system functions. If these data can be derived, then the effect of malfunction on crew workload and manning of the system can be projected.

EFFORT NO. 13, DEVELOPMENT OF SYSTEM MALFUNCTION ASSUMPTIONS

DISCUSSION OF THE SST STUDY EFFORT NO. 13

The assumptions formulated for relating current jet malfunction data to SST malfunction effects have been presented in Chapter 3 of Reference 2 and are not repeated here. It is important to point out that the primary objective in developing such assumptions was not to imply definite SST reliability or malfunction statistics, but rather to provide a basis for analyzing potential effects on manning if SST system failures follow the same pattern as current jet system failures. Whenever SST system reliabilities can be validly established, effects on crew workload and manning can be more directly calculated.

SUMMARY OF EFFORT NO. 13

SST STUDY APPROACH	A GENERAL CREW REQUIREMENTS STUDY
EFFORT NO. 13. Development of system malfunction assumptions	EFFORT NO. 13. Development of system malfunction assumptions
INPUTS: 1. Frequency and distribution of malfunctions 2. SST system design characteristics OUTPUTS: 1. Effects of malfunctions on manning METHOD SUMMARY: 1. Develop modes of malfunction 2. Develop assumptions for relating current jet failure data to SST 3. Determine key functions and associated systems to obtain estimates of function MTBF 4. Determine increase in manning due to key malfunctions	INPUTS: 1. Frequency and distribution of malfunctions 2. System design configurations OUTPUTS: 1. Effects of malfunctions on manning METHOD SUMMARY: 1. Develop a maintenance concept 2. Determine MTTR and/or reconfiguration workload 3. Determine increase in manning due to malfunctions

DISCUSSION OF A GENERAL STUDY EFFORT

In general approach, the techniques for accomplishing this effort are again quite complex and beyond the scope of the present study. In essence, it is necessary to proceed through the following three steps. First, a maintenance concept must be developed. The maintenance concept should identify the level and location of various maintenance activities associated with each function, as well as the implementation concept for these activities. This implementation concept or concepts must include a description of the crew (or technician) participation in implementing maintenance for each function. Second, the mean time to repair and/or reconfigure the function based on the specific implementation concepts must be determined in order to project the workload associated with each malfunction and the maintenance concept relevant to resolving the malfunction. Third, the increase in manning due to malfunctions may then be determined by assessing or determining a workload associated with each malfunction and the mean time to repair or reconfigure the malfunction.

EFFORT NO.14, CREW COMPOSITION ANALYSIS

DISCUSSION OF THE SST STUDY EFFORT

As a final effort in the SST study, a preliminary crew composition analysis was performed. This analysis was not conducted in order to recommend the size or individual qualifications of crew members, rather it was aimed at investigating workload distributions which might be readily converted to actual performance combinations for simulator research. The general approach and techniques used for this effort of the SST study are presented in Chapter 4 of Reference 2 and will not be repeated here. The approach used for the SST was, however, very similar to the approach discussed for a general crew requirements study in the following paragraphs.

SUMMARY OF EFFORT NO. 14

SST STUDY APPROACH	A GENERAL CREW REQUIREMENTS STUDY
EFFORT NO. 14. Crew Composition Analysis	EFFORT NO. 14. Crew Composition Analysis
INPUTS: 1. Crew workload-manning profiles for automatic and manual implementation concepts 2. Effects of malfunctions on manning OUTPUTS: 1. Crew workload-position estimates METHOD SUMMARY: 1. Determine a reasonable range of crew positions 2. Derive criteria for grouping activities and functioning 3. Group activities and functions 4. Derive cumulative workload for each group of functions and activities 5. Distribute activity and function groups into positions. Repeat for each different number of positions 6. Develop position-workload profiles for automated and manual implementation concepts 7. Review profiles for increased manning due to malfunction	INPUTS: 1. Crew workload-manning profiles for automatic and manual implementation concepts 2. Effects of malfunctions on manning OUTPUTS: 1. Crew workload-position estimates METHOD SUMMARY: 1. Determine a reasonable number of crew positions 2. Derive criteria for grouping activities and functions 3. Group activities and functions 4. Derive cumulative workload for each group 5. Distribute activity and function groups into positions 6. Develop position-workload profiles for automatic and manual implementation concepts 7. Modify profiles for malfunction effects

DISCUSSION OF A GENERAL STUDY EFFORT

The usual procedure for determining positions and manning in systems is to (1) determine task, skill and knowledge requirements, (2) group the tasks with similar skill and knowledge requirements into positions (to minimize training), and (3) determine manning by examining tasks on each position and, therefore, number of persons per position. The approach suggested here is somewhat different in that manning requirements are determined first, a reasonable number of crew positions is then selected commensurate with the total manning requirements, and finally, the total system performance is distributed into the various position configurations.

If the method described thus far has been followed, the results of Efforts No. 11 and No. 13 provide an analytical estimate of the total manning required for system operations and malfunction effects. This total manning estimate may then represent a nominal value for the total number of crew members or positions which can be expected. A reasonable number of crew positions may also be influenced by systems constraints as, for example, in the case of the SST. Here the total number of crew positions will be two, three or four, and cannot practically be ten, for instance. In the general case, however, manning estimates should allow identification of a reasonable range of crew positions to be investigated.

Next, it is necessary to derive criteria for grouping activities and functions. The five criteria listed and defined below are general criteria which can be applied to activities and functions in order to group them.

1. <u>Sequence and temporal considerations.</u> The sequential nature of events during operation may be a requirement for clustering functions into a single position. Similarly, consideration

should be given to avoiding assignment of functions to a given position when the functions occur simultaneously.

2. Equipment considerations. Functions relating to a particular equipment configuration should be grouped so as to involve the smallest number of positions.

3. Homogeneity of qualifications. The skill, knowledge, and personnel characteristic requirements for any one position should be as homogeneous as possible. This refers to both homogeneity of content area and homogeneity of training level. Clustering in terms of homogeneity of qualification also conforms with a logical training and selection program.

4. Constraints imposed by the system design. A number of constraints upon the grouping of functions into positions may be imposed by (a) the location required for a certain position, (b) the assignment of responsibility to certain positions, and (c) the interaction of certain functions even though they may not be sequential. In the case of the SST, the system design constraints are principally those of "piloting" the aircraft which must be done from the two positions located in the front of the flight deck (normally the pilot and copilot position).

5. Compatibility with personnel classification and career structure policies. It is desirable that each position have a bona fide fit to an existing or potential career field.

The criteria above should be applied to all activities and functions in order to group them. Once groups of activities or functions have been obtained, the cumulative workload for each group should be determined. The groups of activities and functions may then be distributed among the available positions. This distribution of groups of activities and functions must be done for each possible number of crew positions. The same criteria used to group the activities and functions initially may also be applied to distribute the groups of activities and functions into various crew positions.

When all of the activity and function groups have been distributed into positions, workload profiles may then be developed for each position in a manner similar to the profiles developed in Effort No. 11, that is by summing the instantaneous workload values over each unit of time for the entire time line base.

Once activities and functions have been distributed into the various crew position configurations, the basic qualifications required to man any position can be deduced from the basic skills and knowledge associated with performances assigned to that position.

REFERENCES

1. Price, H. , Behan, R. , & Ereneta, W. Requirements and constraints of potential roles of supersonic transport crews. Washington: National Aeronautics and Space Administration, CR-146. January 1965.

2. Price, H. , Honsberger, W. , & Ereneta, W. A study of potential roles of supersonic transport crews and some implications for the flight deck. Vol. I: Workload, crew roles, flight deck concepts and conclusions. Chatsworth, California: Serendipity Associates. Final Report for Ames Research Center, National Aeronautics and Space Administration, Contract NAS2-2209. November 1965.

3. Price, H. , Honsberger, W. , & Ereneta, W. A study of potential roles of supersonic transport crews and some implications for the flight deck. Vol. II: Feasible automated and manual implementation concepts for SST activities and functions. Chatsworth, California: Serendipity Associates. Final Report for Ames Research Center, National Aeronautics and Space Administration, Contract NAS2-2209. November 1965.

4. Story, Anne. Man-Machine system performance criteria. Report ESD-TR-61-2 for Operational Applications Office, Deputy for Technology, Electronic Systems Division, Air Force Systems Command, USAF, Bedford, Massachusetts. May 1961.

5. Price, H. , Smith, E. , & Behan, R. Utilization of acceptance data in a descriptive model for determining man's role in a system. Washington: National Aeronautics and Space Administration, CR-95. September 1964.

6. Hanes, L., Ritchie, M. & Kearns, J. A study of time-based methods of analysis in cockpit design. Wright-Patterson AFB, Ohio: Aeronautical Systems Division, Dir/Aeromechanics, Flight Control Lab. ASD-TDR-63-289. May 1963.

7. Air Force Systems Command. System engineering management procedures. AFSCM 375-5. December 1964.